DÆDALUS

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Science and Technology in Contemporary Society

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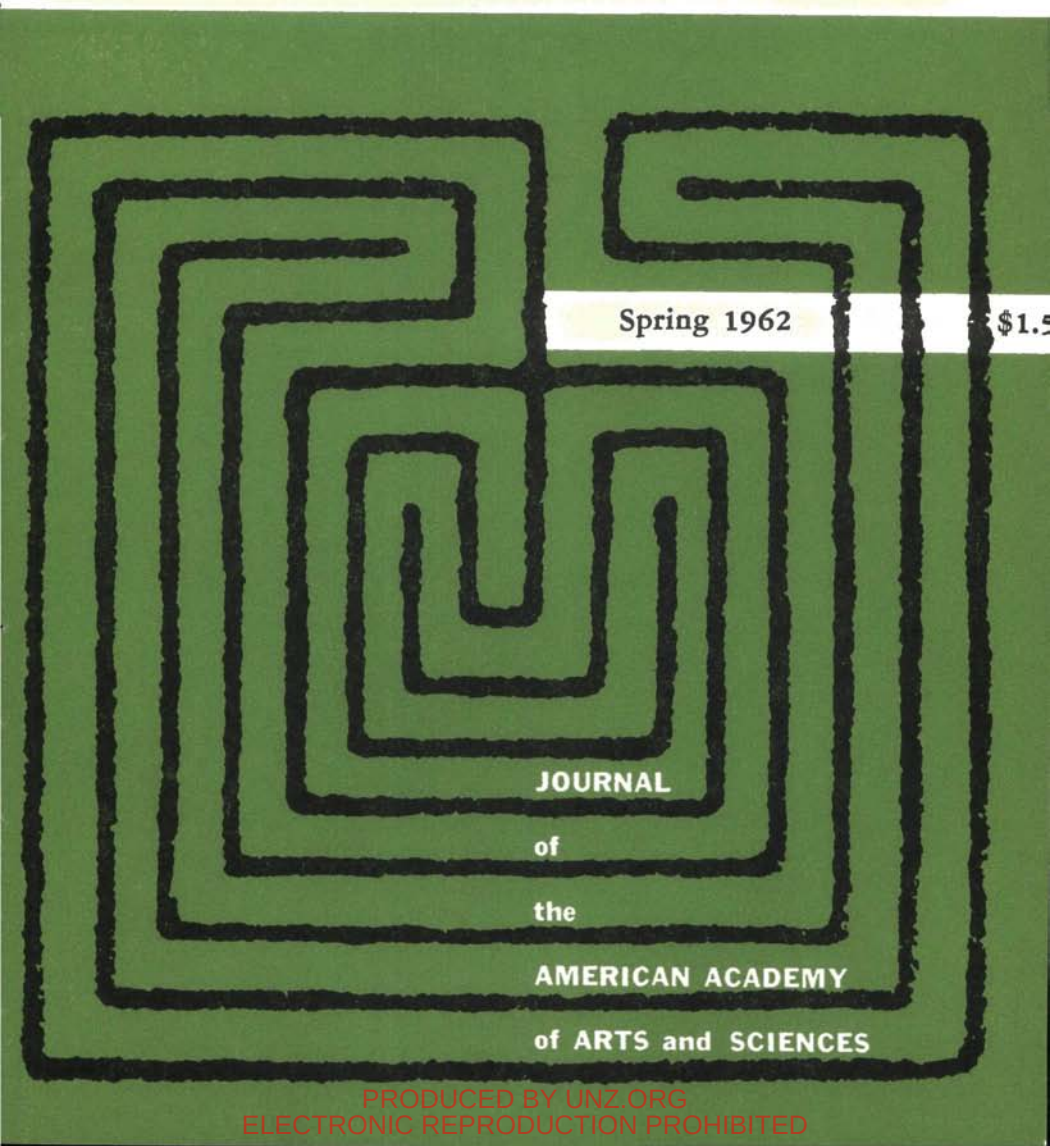

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Preface to the Issue "Science and Technology in Contemporary Society"

In April 1960 the Massachusetts Institute of Technology celebrated its centenary. Distinguished scholars from this country and abroad came to listen to and discuss papers on the general topic, "Science and Engineering Education." Dr. Julius Stratton, the President of the Institute, expressed the spirit of the occasion when he said, "Science, in sum, gives us knowledge and power of action. It tells us what we *can* do; we must turn elsewhere to learn what we *ought* to do. There is no certitude in man's affairs, and we learn by trial and error; but the errors are becoming increasingly expensive. For guidance we must turn to the accumulated record of all human experience, to the ethical teachings of our religious faiths, to the understanding revealed by systematic study of human behavior. These are the strands that through education must be interwoven with science and technology to form the fabric of a single culture, and the hope of a harmonious and peaceful world."

Dædalus is privileged to publish seven of the papers prepared for the Centennial of the Institute. These essays explore themes that would have seemed less urgent even as recently as twenty years ago. It is a measure of all that has happened in the last two decades that this should be so. Professor Aron raises the question as to whether the developments in science and technology have not made certain democratic political processes anachronistic, and whether the control of political society in the present circumstances can be safely entrusted to ordinary citizens who do not pretend to be specialists in the complex areas which they must handle. Sir Eric Ashby is concerned with the education of the administrator in contemporary society. Recognizing the uniquely important role of an occupation whose function is only now beginning to be understood, he seeks to describe the skills that administration requires and the ways in which men ought to be trained for these new roles. Mr. Aldous Huxley asks quite simply, "Just how good is modern education? How

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successful is it in helping young people to make the best of all the worlds which, as multiple amphibians, they have to live in?" Mr. Huxley's recommendations for change are not those that are traditionally given when these questions are raised.

Dr. Kubie, Professor Lewis, Dr. Morison, and Dean Brown, though writing on discrete topics, are all concerned with aspects of two fundamental problems. The first is to determine what educational innovations are required in highly organized industrial societies to maximize technological and scientific invention, thus taking advantage of possibilities opened by recent discovery. The challenge is to provide education suited to the present needs but also capable of enlisting the energy of talented men and women on whose work scientific progress depends. A quite separate concern, more obviously contemporary in its emphasis, is to devise suitable educational schemes for underdeveloped countries. The recommendations and injunctions in this area are both general and specific. The responsibility for their implementation rests as much with the developed countries as with those for whom they are designed.

Professor Holton, Editor of the American Academy of Arts and Sciences, writes on the rapid changes of science as a professional pursuit in our time; this is in part a study of the conditions inside as well as outside science that appear to be necessary to its continued excellence. The essays by Professor Manuel and Father Ong, while not written specifically for this issue of *Dædalus*, "Science and Technology in Contemporary Society," treat matters so clearly relevant to the topic that to include them seemed both natural and reasonable. We are pleased to be able to revive the departments, "Work in Progress" and "Opinions and Issues" with these distinguished contributions.

S. R. G.

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RAYMOND ARON

The Education of the Citizen in Industrial Society

Modern societies present certain characteristics previously unknown, and observers agree in putting these original traits of modern civilization to the credit (or debit) of science. In the United States, the application of scientific knowledge has enabled less than ten percent of the work force to produce enough food for the entire population. Science has enabled machines to replace the hand and, in certain circumstances, the brain of man. The fundamental needs of mankind have remained the same: food, lodging, clothing, transportation, and communication. Technology has simply furnished the means both to lighten the effort necessary to satisfy these needs and to diversify and multiply the means of satisfying them. What are known as durable consumer goods correspond to these two categories: some are household appliances, which are to the housewife what machines are to the worker in the factory (vacuum cleaners, refrigerators): others permit the fulfillment of the secular and previously utopian desires to triumph over space, to be suspended in mid-air, and to be everywhere at once (radio, television, automobiles, and airplanes).

Science also has simultaneously created new means of destruction. But societies, at least since the dawn of so-called higher civilization, have always fought one another. Atomic and thermonuclear bombs correspond also, then, to a need or an ancestral desire of man, the need or desire to be master of the life of his fellows. If this interpretation seems shocking at first glance, it is easy to replace it with a neutral formula which is incontestable: the manipulation of the forces of nature could not fail to create as a by-product a capacity for destruction utilizable for war and proportional to the capacity for production.

Scientific or industrial societies (the latter formulation is the

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more common) are not characterized solely by visible traits recognized by all observers, such as a modified division of labor, industrialization, urbanization, increasing per-capita income, or the creation of an artificial milieu in which the existence of the city-dweller and increasingly even that of the country-dweller unfolds. Industrial society is subject to the dynamism of the industry in which it takes pride. Scientific knowledge no longer increases by accident but by necessity. Research is organized, and it mobilizes thousands and hundreds of thousands of "scientific workers." Now, technology is inevitably refashioned by the progress of science, and society in turn is transformed by the renovation of the techniques of production. The true permanent revolution which modern societies are undergoing is the scientific revolution.

The problem we should like to pose in the following pages is that of the adjustment of the citizen to scientific society. Is the very concept of the citizen compromised by the complexity of the society to which he belongs? What kind of training should the citizen receive to enable him to fulfill his functions?

Did classical political theory presume an education and judgment on the part of the citizen which few voters today possess? This proposition, frequently put forward, is probably true, but it must be complemented by another. Never did the thinkers of the Western tradition believe that *all* the members of the collectivity could become citizens, never did they admit that all individuals were equally capable of attaining citizenship and the wisdom it requires. In fact, before the democratic era and even somewhat since, philosophers spontaneously accepted a distinction between the elite and the great number of people—whether they attributed this distinction to inherent individual inequality or to an inequality in the conditions of life.

If today in the mid-twentieth century we feel a certain amount of disappointment, it is less in relation to yesterday's reality than to yesterday's hopes. Democratic philosophy postulated as a starting point the equality of all members of the collectivity, the right of all to receive an education which would make conscious citizens of them. But the most fervent democrats have not explicitly held that equality of rights and education would eliminate the natural inequality of talent and individual capacity. Our disappointment—if disappointment it be—is based on two facts: the opportunities of individuals remain very unequal even in the most prosperous

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societies, and the capacities of individuals are even more unequal than one had tended to believe.

Let us suppose that all children from the very first are enrolled in the same school and that their careers depend exclusively on success in their examinations. Compared with the children of workers, the children of the bourgeoisie would still be privileged because of their family surroundings. Much remains to be done to reduce the privileges from which some benefit and the obstacles which others must surmount.

The inequality in educational opportunity which derives from social inequality is perhaps less discouraging for the enthusiasts of the democratic faith than is the inequality which is irremovable, that of individual capacity. All normal children are capable of attaining a certain level of knowledge, but for each child there exists a level which is not known in advance but which is discovered to be insurmountable. The number of original and creative minds is small; the number of persons capable of absorbing the whole of a scientific discipline is far from large. In other words, apart from the fact of social inequality, the inequality of intelligence is a fact of nature which will resist all revolutions (until the conceivable but improbable day when the biologists succeed in manipulating genes).

While recognizing the inequality of education and of talent, we would be wrong to forget that the mean level of instruction in modern society is higher than in any other known. Throughout the entire world, Westernization or modernization has meant obligatory primary school—education which is universal, at least in theory. (That the Western nations have not applied to their colonies the principles on which their own societies were founded is equally incontestable.) The Meiji revolutionaries included primary school for all among the first measures necessary for the modernization of Japanese society.

In fact, in Western, particularly European, societies, what is striking is the slowness with which secondary and higher education has diffused. It has done so throughout the twentieth century and at an increasingly rapid rate since World War II. Only in the last two decades or so have the leaders of the state and the economy understood that a modern society needs workers who are increasingly skilled. No one can participate in an industrial enterprise without a certain amount of training. As a general rule, factories need increasingly numerous administrative or technical staffs. The number of workers for whom primary education is insufficient is

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rising. In others words, the economy itself imposes the necessity of giving to *all* individuals a minimum of intellectual and technical education, and of giving to an increasingly large number of persons a secondary or higher education.

We recall these well-known facts to suggest to the reader a question which is apparently paradoxical but logical: Why should scientific society be incompatible with the obligations of citizenship when it needs workers who are more and more educated? The historical coincidence in the arrival of scientific society and the arrival of democratic society is in no way accidental. Only those societies which base themselves on free labor and not on slave labor can be democratic (if one calls democratic those societies which tend to grant their members participation in the state or culture). In this sense, Auguste Comte was right in defining industrial society as free labor and social mobility and consequently in his insisting on the democratic nature of industrial society.

The reader may immediately form an objection. Workers in scientific societies are certainly more educated than those in past societies, but are not modern societies more complex and especially more changing, so that, in spite of a better education, the common man is less capable of understanding the social milieu in which he lives than was the illiterate peasant or worker of past centuries? This objection contains without doubt a partial truth: it is possible that social complexity has increased at a more rapid rate than has the education of the citizen.

The central difficulty seems to me to be the following. The peasants or workers in traditional societies were integrated into kinship and locality groups. Most of them lived a simple existence and left a world which in their eyes was similar to the one they found when they became men. Not that there had been no changes; traditional societies obviously had a history, but that history was relatively slow, and when it was not, it was catastrophical. In our times, rapid change is normal, not exceptional. The essence of a scientific society is change, whereas the essence of traditional societies was conservation. To most men, however, the transformation of the social milieu, a process which is often painful and a source of suffering, remains abnormal. Adjustment and social integration have come to require the acceptance of instability.

Does this mean that because of the complexity of his milieu the American citizen today is less capable of fulfilling his civic duties than was the citizen of yesterday? I cannot subscribe entirely to

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this opinion, which is both common and pessimistic. The first duty of citizens is not to resolve the problems of the collectivity, not even always to understand them fully; rather, it is to choose their representatives. Do Americans today choose better or worse when they choose their President, their Senators, their Representatives, their judges or their mayors? (The same question could be asked in relation to the French or the English.) I am not sure that anyone, not even the specialists in political science, can give a categorical answer to such a question, but personally, if I had to answer, I would insist on the apparent constancy of electoral conduct: the *homo politicus* in his capacity as a voter seems little different in the mid-twentieth century from what he was at the turn of the century. The Germans freely gave more than a third of their votes to Hitler and his party; the French in 1956 gave nearly 15 percent of their votes to the party of Pierre Poujade. Senator McCarthy managed to dominate the political scene of the United States, at least in appearance, for a number of years. The national hero, such as Hindenburg, Eisenhower, or de Gaulle, is acclaimed and elected. The common man, whether he continues his studies to the age of twelve, fourteen, or sixteen, seems to me to have remained essentially the same as a voter. If he has changed, it seems to me that the change has been for the better rather than the worse.

In the United States, the voters distinguish more and more between parties and persons. During the 1960 elections the same state could choose by an immense majority a Democrat for President and a Republican for Senator. The phenomenon is not new, but it would appear that it is becoming more accentuated. Now the capacity or the propensity for discrimination (one chooses such and such a person because he is what he is, and not because he is a member of the Democratic or Republican Party) is considered a symptom of political maturity. (It does not follow that this discrimination is always beneficial to the functioning of the political system.)

It will still be said that the duty of the citizens is not exhausted by their election at regular intervals of "representatives." In a regime such as that of the United States, at least three other functions were observed by Alexis de Tocqueville more than a century ago: the participation in public affairs at a town or county level, the creation of voluntary associations for the study or solution of problems faced by the collectivity, and influence exercised over the governors of the republic. Let us call these three functions *self-government*,

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collective initiative, and *enlightened public opinion.* Have these become paralyzed? Have they fallen into disuse in the era of scientific society?

As to the first two, the answer seems, broadly speaking, to be negative. Citizens continue to be capable of conducting public affairs on the local and county level, they continue to take initiatives in studying or attempting to resolve problems, some of which are national, others international (the limitation of armaments), still others, social and local (juvenile delinquency in a particular community). It may be that these two functions are not carried out with the same ardor and the same vitality: the role of experts is greater, that of amateur and well-wishing citizens, more difficult. The federal government has replaced local government in many fields, and it undertakes to do administratively what local communities previously did voluntarily and politically.

The fact remains, nonetheless, that the American citizen in the mid-twentieth century continues to elect representatives, to participate in the running of local affairs, and to take initiatives on a local or national scale, perhaps not better but certainly not worse than his fellow citizens did half a century ago. Must we conclude that the problem we have raised—the education of the citizen in a scientific society—is a false problem? Not at all. But the problem goes beyond our preceding remarks.

First of all, we have not answered the question suggested by the third function of the citizen: Does the influence of enlightened public opinion have the same influence as in the past on the leaders of the republic? At this point we begin to have some doubts. On the question of war and peace, does enlightened but not expert opinion still have the same meaning and the same authority as yesterday? Does the justified horror inspired in all by atomic war still permit amateurs to weigh reasonably the risks and the alternatives? Is public opinion not forced to underwrite successively both extreme optimism (the bomb has killed war) and limitless pessimism (a new war would be the end of the world), because the theory of war and peace in the atomic age has become too complex and too subtle for the common man—as complex, in a sense, as ballistic missiles or the bombs themselves?

The question just formulated in relation to war and peace could be asked with respect to many problems of government, whether in scientific research, economic planning, or the conservation of natural resources. In other words, if the problems of government in

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a scientific society are truly scientific problems, then is not democracy (that is, the election by amateurs of amateurs to positions of leadership) a sort of attack on common sense and ultimately a ruinous absurdity? Can a scientific society be governed by nonscientists? Or if scientific society must continue to be governed according to the democratic principle (the election of amateurs by amateurs), what education must the amateurs receive to enable them to maintain their role as voters or as rulers?

We have given an intentionally simple and categorical expression to the problem. The problems of government are *never* problems which are exclusively scientific. On the other hand, the scientific character of certain problems in government is itself complex, that is to say, it does not depend on a single scientific discipline but sometimes on many.

Politics is not reducible to a science because the selection of a group of persons who will be called upon to decide for everyone does not involve a method which is fully amenable to reason. Election satisfies the ideal that men should govern themselves, but it clearly does not give any guarantee that those most worthy of governing will be elected. Moreover, the qualities necessary to obtain votes are not those of the statesmen (although they are not incompatible). Even if one could put the philosopher-king in power, he would still need something besides wisdom in order to govern. To govern is to take a just decision, but it is also to make it acceptable to the majority of the citizens; it is to contain opposed interests and to make concessions to the prejudices of some and to the nostalgia of others. In this respect, the governing of scientific societies does not differ fundamentally from that of nonscientific societies.

It nonetheless presents some original traits which are related to the scientific age. In a simplified analysis, I would say that the rulers of our era have to resolve three types of problems which did not exist (at least, to the same degree) in the past and which are "scientific," but in three different ways. The first category is that of properly economic problems: What must be done when a recession begins or when gold reserves begin to diminish? The decision must be made by the rulers, but it requires intellectual training. The second category of problems originates in the natural sciences. In what direction should scientific research be directed? How should available funds be allocated among different institutions? Given the actual or probable costs of different sources of power in

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a few years, what program should be adopted for thermohydraulic or atomic-power stations? What armament program will promote over a five-year period a maximum of security or, if war breaks out, the best chance for survival? The third category is that of the problems of diplomacy. Should one sign or not sign an agreement with the Soviet Union on the cessation of nuclear testing, even if the means of inspection do not guarantee that the agreement will be respected? The President of the United States cannot be an expert in these three fields, but he must be capable of understanding those who are. Since any able politician, with the help of good luck, can become President of the United States, the question of the education of the citizen is in one sense also that of the education of the President of the United States.

The culture which universities maintain and communicate, far from constituting a whole, is divided into three groups of disciplines: the humanities, the social sciences, and the natural sciences. The classical disciplines of the humanities communicate with the social sciences (history offers, so to speak, a passageway). The social sciences in turn communicate with the natural sciences, either through the use which some make of mathematical and statistical methods (political economy) or because of the influence which the sciences of nature exercise on the evolution of society (in other words, on the objective of the social sciences).

It has been said recently by a scientist-novelist, Sir Charles Snow, that the West has suffered from the duality of its culture, that the men educated only in the humanities have lost contact with the Great Adventure of the West and of the whole of humanity today, the mathematical, physical, and biological sciences. Sir Charles, who himself partakes of both cultures, has denounced the impoverishment of the individual which results from the ignorance of one of these cultures, as well as the dangers which would be created by the predominance of humanistic education in Western society, especially among government personnel. Turned toward the past, the humanist is willingly pessimistic about the future. Turned toward the future, the scientist cannot help but be optimistic, at least in what concerns the progress of science and the development of technology.

It is not my intention to discuss here the problem of the two cultures in all its breadth, and so I shall limit myself to some general remarks. It seems incontrovertible to me that countries like France and England suffered for a long time, and perhaps in certain

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respects suffer still, from the prejudice which declares a classical education to be indispensable, but not a mathematical one. In France in 1923, a truly reactionary reform of secondary education increased the emphasis on the humanities at the expense of the sciences and strove to force all the good students to learn Greek and Latin, even if they were heading for a scientific career. There are still some English universities which will not open their portals to those who do not know Latin. In our time, the lack of scientific education is more troublesome than is the absence of a humanistic education, for two reasons. It is more difficult for a humanist to obtain a scientific education late and alone than for a scientist to gain an appreciation of humanist culture. The latter is to a large extent open and offered to all. On the other hand, in our scientific society it is more serious to be a stranger to the spirit and the methods of science than to be ignorant of the languages or literatures of antiquity.

These two propositions, nonetheless, require some reservations or qualifications. Humanistic culture is of relatively facile access, but true culture does not reveal itself except after long familiarity. A mathematician or a physicist does not need an apprenticeship to discover the literature or the art of today or yesterday, whereas a Latinist or a Greek scholar would need an apprenticeship to penetrate the universe of modern science. But it remains to be seen which mathematicians or physicists will attempt to discover humanist culture and to what extent they will be affected by this eventual discovery. Humanist culture in essence is less a sum of knowledge than a way of thinking and being.

Furthermore, the dangers of an exclusively scientific education, although less obvious than those of an exclusively literary education, exist, however, and have been underscored more than once: a belief in the all-powerfulness of science, a misunderstanding of data not reducible to the scientific method, an ignorance of historical traditions and social complexities, and so on. There is today hardly any debate on the necessity to add to scientific education a minimum of humanistic or sociological education.

Having made these banal remarks, we return to the central issue: Is the Senator or the President, who is normally an amateur, capable of taking political decisions which involve complex scientific considerations? How can he be prepared for this task? In other words, how can the citizen be prepared to live and act in a scientific society? I have no doubt but that the answer given by numerous

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scholars and sociologists to such questions would be negative: the amateur will never be capable of taking such decisions, he will never receive the necessary education, and public opinion is definitely incapable of understanding current administrative and governmental problems. Personally, I am less pessimistic than many.

Let us begin by considering the problems which relate essentially to the social sciences, to the economy for instance. (What to do in case of recession?) I should like to observe first of all that economic problems have been studied nowadays by men who come from the natural sciences. Statistical and mathematical techniques have rendered considerable services and permitted some obvious progress; but when it comes to the taking of a decision at a given time and place, uncertainties remain, even beyond the resistance offered by interests and the prejudices of men and classes. It is therefore not wrong that the decision should be taken by an "enlightened amateur." And this is what the politician of the Western democracies usually is. He is capable of following the arguments, of understanding the concepts, of economists. Will the choice he makes from among the arguments of the different groups be risky, even assuming that it is not falsified by partisan considerations? Certainly it will, but if the President were a professional economist, this alone would not suffice to guarantee a correct decision. On the whole, the risks of error would probably be greater. An economist has convictions based on his personal labors. He would be frequently inclined to take measures dictated by his doctrinal preferences and possibly to ignore certain factors or certain objections. In brief, the present formula—regular consultation of the experts, and decisions ultimately taken either by enlightened amateurs or by committees composed of experts and semi-amateurs—does not seem irrational to me. In any case, it is the only possible one in a Western democracy.

It can be improved in three ways. In certain countries the communication among academic economists, the directors of the economy, the civil servants, and the politicians is insufficient. Theoreticians and practitioners are either unaware of one another or despise one another. Politicians do not want to know or listen to the experts. Now, the circulation of ideas and the contacts between specialists and amateurs seem to me to be both indispensable and fruitful. In the second place, it is best to avoid the intellectual fossilization of scholars or of amateurs, for this inclines both not to question the ideas received in their youth. It is frequently said that

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scholars retain the philosophy they learned in school, that is, one which dates from a previous stage of knowledge. The same delay of ideas with respect to reality in economic matters threatens both specialists and amateurs. During the 'thirties, statesmen obstinately applied the principles of sound money and therefore worsened the depression. During the first years of the postwar period, Western statesmen, even in England, applied Keynesian precepts, which had been developed and adapted to the situation of crisis, during antithetical periods of full employment and inflation. The most abstract propositions of economic science are perhaps definitely established, but the propositions which serve as the basis for an action program belong to a "middle range" (R. K. Merton's expression), and they are applicable in certain concretely defined historic periods. They cease to be so when the societies are affected by other changes. Let us say that the progressive character of society and the social sciences requires of everyone, expert and amateur, redoubled and continuous efforts aimed at refreshing acquired knowledge.

In the third place, it is indispensable that public opinion—a sufficient number of citizens and, even more importantly, of those who influence the thought of citizens, as writers, journalists, commentators, observers—should be able to understand and consequently to support the action of the governors and the recommendations of the experts. From this perspective, we now return to the problems of education. In certain Western countries, France in particular, the economic and sociological training received by students is clearly inadequate. It is striking that, in a recent report on the causes which delay economic growth, a committee of experts should have prominently listed the lack of economic training.

So long as the problems of government relate more to the social sciences than to the natural sciences, communication remains possible between experts and amateurs. This is not always true when the problems relate to the natural sciences. In the United States, the President now has a scientific advisor in addition to his economic advisors. Perhaps the difficulty lies less with particular technical questions (such as those relating to a program of developing electric power), which can be left to the expert, than with the over-all scientific perspective necessary for the development of the sciences and the correlated transformations of society. Political leaders must be capable of understanding these perspectives as a whole and of orienting their action by taking into account this glimpsed future. As Sir Charles Snow expresses it, humanists have a tendency to

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become "existential," to be satisfied with the present, and to fear the future. The scientists are the men of perspective, the "futurists."

My experience, both personal and as a Frenchman, does not accord fully with the opposition of the "pessimism of the humanists" to the "futurism of the scientists." Not that it is impossible to observe in France the pessimism of the humanists who denounce society and the barbarity of the masses, or the optimism of the scientists who announce for tomorrow universal abundance and the three-day week. But the contrast is not absolute. Some men trained in the humanities have confidence in the future, some scientists are preoccupied by the dangers of nuclear war. Intellectual training and political opinions contribute to determining the attitude of both groups. The discipline called *prospective*—the systematic study of future perspectives over intervals of five, ten, fifteen, twenty, or fifty years—was conceived by an administrator, originally an industrialist, and then a professor who was not a scientist.

In broad and somewhat superficial terms, it is easy to say that the diffusion of scientific culture would contribute to the preparation of politicians and public opinion for the future, and that it would direct their attention to what will be, and surmount the obsession with the present. But I am not certain of this. First, we must consider the risks of the half-culture, of superficial education. It is not always true that a little information is better than no information at all. At least an elementary education is preferable to a total lack of education when the individual is intelligent, when he maintains a constant awareness of his lack of knowledge at the same time as he acquires the sense of what there is for him to discover. Among the heads of firms, some have had the sense of technology and innovation, even though they were in no way (or perhaps because they were not) technicians. The French firm whose technical level is perhaps the highest owes its success to the initiatives of its founder, an artist-painter.

These apparently paradoxical remarks are not meant to refute the common belief that citizens and governors in industrial societies must understand science better and therefore must receive a better education in so far as possible. They tend only to complement this commonplace opinion with a less banal suggestion: the supreme virtue of the mind in a scientific society and in a revolutionary era is perhaps neither one kind of education nor another, but rather flexibility, imagination, the capacity of not being a prisoner of stereotypes, of remaining open to new developments. Is true scientific

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culture favorable to this perpetual intellectual flexibility? Probably, on condition that we add that scientists are men like others and that they are at times the victims of pride, social prejudices, or political passions. And—an additional danger—many of them have a tendency, conscious or otherwise, to give their opinions a scientific dignity these do not possess. Nothing is more difficult for man (whether a scientist or not) than to measure exactly the coefficient of uncertainty he must attribute to his judgments, recommendations, or forecasts.

We now turn finally to the third category of problems, those of foreign policy in the atomic age. These stand at the confluence of the sciences of nature, history, psychology, politics, and so forth. To discuss a deterrent, one must know the destructive capacity of a thermonuclear bomb. But it is also necessary to know how (or whether) it is possible to utilize politically a threat no one wants to carry out. The knowledge of the destructive power of the bomb is given us by physics. What science, however, permits us to measure the probability of the two great powers becoming involved in a thermonuclear war during the next ten years? When the physicist tells us what the cost of a thermonuclear war would be, we believe him. If he affirms that without disarmament, thermonuclear war is inevitable or very probable, he is no longer speaking as a physicist, and his scientific culture does not guarantee the accuracy of his historic forecast.

Debates on foreign policy involve not only quantitative data (what is the surface area which a five-megaton H-bomb will destroy?) and psychohistorical evaluations (what is the probability of thermonuclear war?). They also involve evaluations (which can be more or less precise or more or less certain) of technological developments which are likely to affect a current political decision. For example, the partisans and opponents of an agreement on the halting of nuclear testing express contradictory opinions on the military advantages which one of the parties could obtain from secret tests carried out in violation of the agreement.

The controversy is still more complicated: at each stage we find that qualitative data, quantitative probabilities, and psychopolitical estimates are enmeshed. What is the number of inspection stations necessary to detect secret tests? What will the probability be that one or the other of the parties would attempt to violate the agreement? What will the probability of detecting the violation be? What will the military profits of such a secret test be? And so on.

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There is no doubt that only specialists can succeed in following such a debate in all its ramifications but the difficulty lies more in the multiplicity of arguments and of points of view than in the esoteric nature of the subject. The example we have chosen illustrates one aspect of scientific society: the interpenetration of technology and psychology, of politics and science, which could force politicians to be scientists, and scientists to have a truly politico-historical culture. In the present state of things, the conclusion must be an invitation to caution. The scientist interested in armament and disarmament cannot speak one moment as a scientist and another as a politician. As for the intermediate case of the scientist who formulates reasonable hypotheses, we should adopt an intermediate attitude somewhere between confidence and scepticism.

The regimes we call democratic (if the previous analyses are accurate) are not condemned by the scientific character of modern society. Never has it been true that all the citizens were capable of judging public affairs. Citizens are first of all voters, that is, their mission is that of choosing representatives, and they will not choose worse today than fifty years ago. Democracy will be really threatened only on the day when the representatives themselves, that is, the enlightened amateurs, become incapable of understanding the elements of problems or of taking reasonable decisions.

Has this day already arrived? Personally, I do not think so, and I even continue to believe that political choices can be made only by enlightened amateurs. But the dangers are multiplying: the danger that the ordinary citizen no longer understands the society in which he lives, the danger that the over-all functioning of the economy should appear mysterious to many amateurs or partially informed persons, the danger that the rulers may not have their sense of the future constantly recreated by the developments of science, the danger that the most vital problems on which the survival of humanity depends—these may escape most men simply because of their complexity.

To parry these dangers, some recommend the complementation of scientific education with a literary and historical culture. They are right. Others rise against the separation of the two cultures and recommend giving a scientific education to the humanist. These are equally right. I would be tempted to put the accent less on the content of education than on the intellectual virtues it should inculcate: rigor of method and flexibility of mind; to know enough about science and to know that it is irreplaceable without ignoring its

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real limits; the search for truth and the rejection of dogmatism. These qualities, necessary for the politician and the citizen of industrial societies, are not original, but they are even rarer in our era than in the past.

The rulers of the totalitarian state are not subject to lesser requirements. They also must be enlightened amateurs, capable of making choices while taking into account advice given by experts. But they do not undergo one of the tests which the rulers of democracies must face: how to convince public opinion and overcome the resistance of interest groups. In an authoritarian regime, it suffices that the elite be informed. In a democratic regime, public opinion must be sufficiently informed to permit the rulers to listen to the advice of the scientist. In this sense, democracy in our era remains more than ever a wager on the capacity of man to learn and to understand.

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ERIC ASHBY

The Administrator: Bottleneck or Pump?

WHAT DO LAYMEN need to know about science and its applications? This question has two meanings. It could be taken to mean: what does the layman need to know in his own interest? Or it could be taken to mean: what does the layman need to know in the national interest? The answer to the second question depends on the degree of social responsibility the layman exercises in society. I do not subscribe to the view recently expressed by Philippe LeCorbeiller[1] that "a genuine knowledge of the basic sciences must be the possession of every man." It would be fine if it could be done, but heredity stands in the way; half the population has less than average intelligence, and it is idle to suppose that anyone of less than average intelligence can have a genuine knowledge of the basic sciences. Fortunately, it does not matter. A genuine knowledge of the basic sciences does not help an American to vote in the presidential election; nor does it help an Englishman to decide for or against unilateral disarmament. (Indeed, there is no consensus of agreement on this, even among those people who do understand the formula $E = MC^2$.)

In the days when effective public opinion was the monopoly of a small cultivated elite (at the court of Louis XIV, for example), it was important that those who held this monopoly should be familiar with the currents of contemporary thought. Effective public opinion is now as widely diffused as the franchise. And in both America and Europe the scientific beliefs of the overwhelming majority of citizens who exercise the franchise are hesitant, rudimentary, and naive. But there is no reason to believe that their shortcomings as citizens are due to the inadequacy of their knowledge of science. Consider for a moment the cosmology of the common man. He believes the world is spherical, though he could not

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tell you how to estimate even approximately its circumference. He believes that the earth goes round the sun, but if you cross-examined him, he would cut a poorer figure than Aristarchus in defense of his belief. He believes the moon is nearer to the earth than the sun is, but he has no idea how to demonstrate this. His cosmology is based on hearsay and a vague deference to authority. His knowledge of himself has no better foundation. Evolution, he would say, is "true," though he would be hard put to it to cite any evidence in favor of evolution. When he looks at his own children, he sees signs that heredity follows some kind of a natural law, but he could not describe how the law can be demonstrated. Even those of us who know more science soon reach the limits of what we understand, and find ourselves in the misty regions of what we believe only on authority. My own beliefs about the shape of a protein molecule are not much more respectable than a taxi-driver's belief in a heliocentric solar system.

The number of things a layman believes on hearsay about the phenomena of science is not of much importance to society, although it would be in the national interest to ensure that those beliefs which he does have are fortified by real understanding, and that all who complete a secondary education have shared a common core of education in science. Is it important in the public interest to go further and to ensure—by arranging our pattern of higher education appropriately—that educated laymen should understand some particular science more deeply, and in particular should be familiar with the way scientists think and work? Before answering this question, we must pause to recollect that it is expensive both in time and money to invest in a scientific education beyond the high school. Time and money expended on education in science must inevitably be at the cost of other forms of education. It is obvious that professional scientists should have learned how scientists think and work; but do we really want all educated laymen to undergo a similar rigorous and expensive experience?

Clearly not. Clearly we must keep this enterprise within manageable and reasonable dimensions. To do this, we could draw up categories of laymen who should in the national interest be familiar with science, even though they are not professional scientists. I shall select one kind of layman who undoubtedly falls into this category and discuss what in the national interest he should know about science and (equally important to the national interest) what scientists should know about him.

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The category I select is the administrator. The successful administrator has skills which (despite the striving of academic departments which teach administration) have not been reduced to order and codified in textbooks. Books on how to administer are as unconvincing as books on how to make love. There are no educational prerequisites laid down for the administrator. He may have been through the austere formal training of a classical scholar, or a biologist, or a soldier; or he may have left school at fourteen to lick stamps. But there is no doubt that in many administrative posts he must know his way about the world of science and technology. For the interactions of science and society operate to a very great degree through the administrator. He is the channel through which scientists and technologists modify society and through which they are themselves modified by society. He can promote traffic between the two cultures, or he can block it. That is why I have chosen as my title, "The Administrator: Bottleneck or Pump?"

For the purpose of this discussion, I want to include in the category of administrator the sort of people on both sides of the Atlantic who serve on committees which control or advise administrators: the trustees of universities, members of commissions, boards of foundations, and the like. Many of these men are not scientists by training, but they constantly make decisions which influence the direction of scientific research, which create opportunities for discovery and invention, or which generate a fresh impact of science or technology upon society.

What does the administrator need to know about science in order to function as a pump and not a bottleneck? Let me begin by the provocative assertion that the training commonly given to scientists is not what he needs. Indeed, many scientists do not themselves have a synoptic or an integrated view of science. They live what Frank Greenaway calls "the life of the New Pedantry":[2]

> . . . . We give the label "scientist" to a very large number of men who have no organized view of life at all. We do not call any Arts graduate working on a soap manufacturer's advertising account a "humanist"; we do not think of his education as having so ennobled his mind that his television commercials daily manifest his spiritual descent from Erasmus. Why then should we call any "science" graduate working in the same soap manufacturer's laboratories a "scientist" and imagine his hours of daily hack-work to manifest any spiritual descent from Galileo?

We cannot simply look to scientists to discover what administrators should know about science. Our starting point must be the

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functions of administrators themselves. Consider two sketches of administrators facing problems which involve science.

The first is a university president at budget time. He is under pressure on all sides to include items in his budget. There will not be money enough for all of them. He is wise enough (I pity him if he is not) to surround himself with a committee; but the combined expertise of his committee and himself cannot cover all the decisions which have to be taken: an electron microscope for biophysics or a bore hole for the geologists? a new wing to the organic chemistry department, or a block of flats for married graduate students? He has to consider the prestige of his university; the relative merits of Professor A's memorandum (which dawdles on for thirty pages) and Professor B's (which puts the matter bluntly in a page and a half); the claims of Professor C, whose work is perhaps the most distinguished of any in the faculty but who never gets around to submitting a memorandum at all; the state of public relations with governments (which may favor Professor A's project, even though he is an insufferable bore about it); the alumni, who want an Olympic swimming pool rather than more laboratories; the claims for practical subjects (like production engineering) as against subjects of vaguer worth (like sculpture and music). Upon the administrator's decisions depend the future of Professor B's research on geology, the prospect that married graduate students will come to the university (by virtue of its residential amenities) to work with Professor C, and a host of other consequences, utterly unpredictable. No wonder an American university president once described administration as a strain on the character rather than the intellect!

The second sketch comes from a body which has no exact parallel in the United States: the British University Grants Committee. This Committee receives a block grant from the Treasury of some £40 million a year—with no conditions or restrictions attached to it—and distributes this money among the British universities. The Committee consists of a full-time chairman (who is an economist and was formerly head of an Oxford college) and sixteen members. The members include two industrialists, two administrators of technological enterprises, six professors (covering classics, engineering, history, chemistry, and medicine), three heads of colleges (one from each of Oxford, Cambridge, and London), and two experts on school education. The Committee's main responsibility is to give British universities the money they need for their own plans of

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development, but inevitably the money available does not match the needs, and the Committee has to make decisions, based on its own (largely lay) judgment and the judgment of its advisers. Some of these decisions have profound effects both on scientific research and on society in Britain. Not all universities (to give one example) can have the new Atlas computer. Which universities should have Atlas computers, and on what criteria should this decision be made? It is a decision which may determine the pattern of research in applied mathematics for a decade. A much more momentous decision has to be made as to student numbers, which may affect the pattern of society in Britain for the rest of this century. At present in Britain about one in twenty of the eighteen-year-old age group goes on to a university. There is general agreement that this proportion is too low. The University Grants Committee has been consulting with the universities to discover how many more student places they could provide over the next ten years. But the universities themselves look to the Committee for advice as to how big the over-all expansion should be. Should we in Britain see to it that about one young person in every five goes to college, as happens in the United States? This would mean an annual intake of something like 180,000 students, compared with about 30,000 at present. Or, since we have very different patterns of school and technical education from those in America, should we have a much more modest policy for our universities and admit every year only some 60,000 students?

This decision, of course, will not be taken by one man or even one committee; in the long run the people themselves will decide how many of their sons and daughters will go to a university. But the decision will be enormously influenced by a few small groups of laymen who make what amount to administrative decisions, including the University Grants Committee, and those who act on the recommendations of a committee on further education recently set up by the British government under the chairmanship of Lord Robbins. In particular, the decision these groups of laymen make will profoundly influence the future of higher technological education in Britain, especially whether there shall continue to be two approaches to higher technology: one through the universities, and the other through the colleges of advanced technology and the technical colleges.

In Britain it is widely but vaguely recognized that administrators need to know their way about both the sciences and the human-

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ities. Attempts are made to meet this need by courses in liberal arts for technologists, courses in management and in the history of technology for engineers, and courses in the history of science for arts students. It is my personal view that our attempts are spasmodic, half-hearted (it is difficult to convince many faculties to regard them as more than a frill), imperfectly thought out, and (with a few exceptions) unsuccessful.

Perhaps the whole approach is an unprofitable one. The sheer bulk of scientific knowledge which even a specialist must carry is frightening. Think of the skills which a biophysicist must command nowadays if he is to make a serious contribution to his subject: biology, physics, mathematics, statistics, and even a familiarity with the techniques of light electrical engineering. In considering how to educate administrators, we in Britain are not making a frontal attack on this mountainous problem; rather, we pursue a policy of appeasement, offering a side plate of scientific salad to the humanist and a side plate of humanism to the scientist.

There is another and perhaps a more realistic approach to the problem. It is the daily experience of an administrator that he makes decisions in areas outside his expertise on what a scholar would consider to be insufficient evidence. He has to. For the administrator has to take account of time. It is a dimension which quite properly plays only a subordinate role in a scholar's life; but the administrator cannot disengage himself from the calendar; nor can society disengage itself.

The secret of good administration (that is, of administration which benefits that sector of society which the administrator serves) lies not in the administrator's vast and exact knowledge but in his skill at navigating areas of ignorance. In Robert Bridges' words, ". . . wisdom lies / in masterful administration of the unforeseen."[3]

This proposition has several dimensions. Let us examine them with reference to the making of decisions which affect society and which involve science or technology. To give point and substance to the proposition, let us consider the problems which face the Permanent Secretary of a Ministry of Communications in one of the emergent countries of Africa. I select this example because it sets the problem in its simplest terms; and these indeed are complex enough.

The Permanent Secretary has to advise (often to persuade) his Minister, and his Minister has to persuade the Cabinet or Parliament, to take decisions which will set a course for the whole future

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of an emergent society. Most of these decisions involve technology and, at one remove, scientific research on the one hand and an understanding of society on the other. The paramount social problem facing an emergent country is cohesion—social, technological, and intellectual. At the outset cohesion does not stretch beyond family and tribe. If the country is to be viable in the modern world, cohesion must envelop the nation and ultimately some federation of nations. The instrument to achieve this cohesion is communication.

There must, for example, be a reliable long-distance telephone system. But the Secretary cannot simply decide to import a telephone system from Europe or America; he must know that there are special problems in maintaining electrical equipment in the tropics, and to what extent tropic proofing has solved these problems. A second essential step toward cohesion is to have a reliable system of air travel. This, too, cannot be imported from abroad without a consideration of the special problems of air travel in Africa: the soil mechanics of laterites, for air strips; fuel supply and storage; meteorology, for, since thunderstorms dislocate radio-communication in summer and the *harmattan* from the Sahara diminishes visibility in winter, an efficient and in some respects a novel meteorological service will be necessary. Another instrument of cohesion is radio and television. The Secretary must know about the problems of broadcasting in a primitive country, for instance, that the transistor is a most powerful civilizing agent in a country in which nine out of ten people have no electricity supply and cannot easily get a battery charged.

Around these technical problems there cluster a host of circumstances which the Secretary must include in his decisions. Telephone systems, air services, broadcasting—all these demand hundreds of skilled men. A long-distance telephone system could be put up in three or four years; but it takes nearer twenty years to train the technologists who have to design the system and the technicians who have to maintain it. So the Secretary finds himself involved in educational problems: universities and technical colleges and apprenticeship systems and trade schools. There are still wider educational problems on which he must have views; for all these instruments of cohesion are impotent unless the citizens of a country share a common language. So literacy—the teaching of English or French or Arabic to all children of whatever tribe—becomes essential to the program of his Ministry.

On the Secretary's decisions and advice depend the emergence

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of his country from tribalism and its ability to take its place in contemporary civilization. By virtue of his office, he becomes a channel through which technology flows from the Western world into villages just emerging from the Bronze Age. Sharing responsibility with him are citizens who serve on a Broadcasting Commission, an Airways Advisory Board, and the governing body of a college of technology, a judge, a banker, a couple of professors. He and these others constitute a nexus between science and society in that country—between Faraday and Einstein at one extreme, and at the other millions of tribal families. What education in science does he need?

Clearly, whatever his own expertise may be, the Secretary will still have to make decisions in areas of ignorance. It is to the mastery of this art—the administration of the unforeseen—that his education should be directed. It is, to put it simply, the art of using other men's minds.

The technique of using other men's minds is difficult, much more difficult than the technique of using an electronic computer. But there is an analogy between the two techniques which is worth pursuing for a moment. In both, success depends on proper programing. To use a digital computer, a man requires to know what questions it is capable of answering, precisely what questions he wants to ask, and how the questions should be coded before they are put into the machine. On a much more complex level, this is true of the administrator's use of other men's minds; he must know whether his advisers are capable of yielding the data he requires, and he must know how to code an enquiry so that it elicits an answer relevant to the question in his mind.

Suppose the administrator has to decide whether to set up a broadcasting service in a primitive country. He must know the range and permissible wave length of the transmission and whether transistor receiving sets would receive the proposed radio program. He will have no difficulty in finding an expert who can supply this information; but this expert is not likely to know who will train the technicians to man the transmitter and the tradesmen in the villages who service the receiving sets. To learn this he will have to consult another expert; and he will have to turn to a third for advice over the programs which the proposed broadcasting service would transmit. In what languages? And where will announcers and artists be found? Advice on economics and budget will have to come from a fourth expert. Once more the question will need to be carefully

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coded. The administrator wants to know what the broadcasting service will cost, not whether the state could or should afford it: that is a political problem.

All these fragments of information are finally assembled in the administrator's mind. Each expert's reply is (from the standpoint of the expert) complete in itself. From the standpoint of the administrator, the replies are the raw material from which he now has to create a harmonious picture. His peculiar skill is to balance incommensurables; out of this patchwork of ingredients he has to produce what to him (if he is a true administrator) is a work of art: a decision in which all the ingredients are balanced in a satisfying and convincing way. Like a sonnet or a sonata, the decision is disciplined by certain rules. The paramount rule is that the decision must be politically viable—in the broadest sense of the word "political"; that is to say, it must be easily and reasonably turned into action, for ultimate action is the purpose of the administrator's enquiries.

In the setting of our subject, we may say that the good administrator integrates many diverse technological considerations into a simple formula which can easily be used for executive action for the benefit of society. The bad administrator may fail for any of three reasons: because he cannot elicit appropriate replies from experts (because he does not know how to "program" his questions to them); because, having secured the information, he cannot create a simple and persuasive decision out of it (because his own "integration mechanism" is at fault); or because his decisions underestimate the political component (they may be excellent in theory but they are not viable; they overlook the adage that politics is the art of the possible). The education of administrators should be one which minimizes all three of these causes of failure.

The interaction of science and society, of course, works in both directions. There was a time, a century or more ago, when science was influenced by society only in so far as society created a climate of opinion inside which all but the greatest scientists were confined and had to do all their thinking. Administrators were not middlemen in this traffic of ideas. But today, when science is so expensive and when much of it is paid for by the public, scientists can in the long run do only what laymen will pay for, and the administrator has become the channel through which society influences science. So scientists (and technologists) have to learn how to handle administrators.

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The administration has to be regarded as a complex, delicate, and not always reliable integrating machine which gives much better results if the material put into the machine is carefully coded by the expert beforehand. It is astonishing how many experts fail to appreciate this. Every university president has had the melancholy experience of being "ear-bashed" by one of his science professors who wants a new building, or a computer, or a flock of research assistants, at once—as though all the president needed to do were to get an order book out of his desk and write an order. The request comes with no supporting documents at all, or else it is embedded in thirty pages of irrelevancies typed in single space. It comes (although the professor never thought of this) along with a score of other similar requests. The president has to transform this ill-prepared brief into a persuasive paragraph for his finance committee, which meets in two days' time (and he may well have to do it at midnight after returning from a Rotary Club dinner). If the professor fails to get what he wants, he will say the punch has gone out of the president; it will not occur to the professor that he himself is at fault, because he is incapable of coding his request to the president in an appropriate form.

It is this traffic in ideas which the administrator must be trained to conduct. Let us return to our opening question: how to educate the administrator? His education must equip him to do four things: to know how to code his requests to experts; to teach experts how to code their requests to him; to know how to integrate the replies he gets into a simple decision; and to know how to transform this decision into action. The administrator in action, in the category we are considering, might therefore be described as a machine which integrates and transforms into simple decisions two-way messages between science and society, and which can estimate probabilities in areas of ignorance.

There is no cut-and-dried curriculum which provides this equipment, of course, nor would I have the impertinence to propose one. What I am prepared to suggest (as a basis for discussion only) are certain ingredients in the higher education of administrators. All such suggestions suffer from two inevitable weaknesses. The first I have already described, namely, that the art of administration is to make viable decisions in areas of ignorance, whereas our theories of education are concerned primarily with the transmission of knowledge. The second weakness is that administration is a career for the mature man and that no one can predict at the stage of

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formal education which pupils will become administrators and which will not.

Consider for a moment the difficulty of knowing who the administrators are going to be. The capacity for administration is not always evident at college. Some young men who think they would like to become administrators are hopelessly unqualified in personality for the job. Many young men who embark in all sincerity on careers as research workers, scholars, technologists, or teachers will in fact become admirable administrators. So, on the one hand, there cannot (and should not) be undergraduate courses in administration; on the other hand, those who design undergraduate curricula can safely assume that a substantial proportion of their pupils will, whatever they study and whatever their careers are between the ages of twenty-five and thirty-five, end up as administrators; and many of them will be concerned with science and technology. How can this assumption be taken into account? I select two suggestions, one chiefly appropriate for those who will not have careers as working scientists before taking up administration, the other for all who may become administrators.

For administrators who have not themselves been working scientists, there are certain peculiarities about scientific work which they need to know. The first is the scientist's attitude to time. The administrator, when he comes to a crossroad of ideas, must decide which road he will take, even if there is no signpost and even though he has no map. The one alternative which he cannot contemplate is to sit down and hope someone will come along who knows the way. Moreover, if an administrator selects the wrong road, the chances are he will be committed to following it wherever it leads him; very often there can be no going back. The scientist is under no compunction to decide which way to go until he has a map. He can sit at the crossroads to watch and wait as long as he cares. And if he does select the wrong road, he can retrace his steps half a dozen times if necessary. Associated with this peculiarity in the way scientists work is a peculiarity in the way they assess the value of their work. There is no simple graph between effort and return, between investment and profit. If you double the numbers in the research laboratory, you cannot assume that the research done will be twice as valuable. The very technique of pausing at a crossroad of ideas until the way becomes clear makes it impossible to predict the velocity of scientific advance. So the scientist measures success by what we might call faith in the jackpot: faith that once every

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ten years or so something will be done in the laboratory which "pays" (in importance, in prestige, or perhaps just in cash) for all the work done in the laboratory over the last fifty years. Surprisingly often, this faith is justified.

These are just two examples of an approach to thought and action which is taken for granted among scientists. It is an approach which is part of the general strategy of science. Any administrator who is acting as a channel between science and society must understand this approach and be in sympathy with it if he is to fulfill his function. He must "think himself into" the way scientists work. To do this, it is not necessary for the administrator to have been a practicing scientist himself; indeed, to make such a requirement would be a very wasteful and expensive way to train administrators concerned with science, though it is a blessing to science and technology that some men reach administration through that path. I believe there could be a very satisfactory alternative, namely, a course in the general strategy of science which selects problems requiring the minimum of jargon and technical knowledge and which analyses the history of attempts to solve such problems. One immediately calls to mind President Conant's famous case histories and his essay on the tactics and strategy of science; but I am thinking of something at once more modest than this, and more concentrated, something with far less of a sweep in history, concentrating much more on the tracks of thought made by the investigator as he tackles a single circumscribed problem—for example, the effects of the length of the day on flowering.[4]

This step-by-step recapitulation of discovery would be the backbone of a course in the strategy of science. It would include case histories to illustrate the importance of craft in scientific research and the part played by craftsmen and technicians. (If you doubt the value of this ingredient for the education of administrators, try—as I once had to try—to convince a government department that a vacuum glass blower commands higher pay than a janitor.) It would include episodes in the history of science selected to illustrate the immense part which failure plays in discovery (Ehrlich's researches on the selective toxicity of dyes is an example) and the frightening inertia of ideas which delays discovery (Conant's case history on phlogiston is a good example of this).

Another ingredient of this education should be a study of probability theory and statistics, taken as far as the student's mind can be stretched. For administrative decisions are in fact exercises in

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probability theory. This was recognized by Laplace a century and a half ago.[5] It is true, of course, that there are too many degrees of freedom and too many unknowns in the data used for administrative decisions for them to be treated statistically; but it is important for the administrator to know the part played by probability (as contrasted with certainty) in scientific research and to realize that his own decisions rest on much more complicated but analagous estimates of probability. The "masterful administration of the unforeseen" is in fact success in the taking of calculated risks.

Finally, a course on the strategy of science should include some understanding of the organization of science. Men who are going into industry, government service, or academic work should know (or know where to find out) how scientific work is financed and where decisions on policy are taken—the decisions which affect the financing of science or the applications of science to social needs. All this could, I think, be built into a course which would have cohesion and depth. It might not, at the time it was taken, seem to have much relevance to the careers the students hope to follow; but ten years later, when the student finds himself a scientist becoming entangled in administrators, or an administrator having to deal with scientists, memories of a course on the strategy of science might rise to the surface of his mind and revive his interest in mechanisms for the flow of ideas between science and society.

So much for one ingredient of an administrator's education. The second of the two mentioned as a basis for discussion is more pragmatic and is appropriate to the postgraduate stage.

Administration (as I said at the beginning) is an uncodified art. Therefore, the only sure way to learn administration is to administer. Suppose one were to bring a group of young scientists and young would-be administrators together and ask them to tackle an exercise in administration involving science. What would the result be? Surely, that they would learn that there are techniques for solving administrative problems; that administrators, no less than physicists, have an expertise; and they would encounter under conditions of tutelage some of the rudiments of decision-making. The suggestion is worth a trial. There is no lack of models, for what I have in mind is no more than a variant on the case-study technique of the Harvard Business School; a similar approach to an analogous problem has recently been published by Z. M. T. Tarkowski and A. V. Turnbull.[6] The success of the course would depend on a sustained and informal exchange of views among members of a small

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group of graduates, some of whom were nonscientists embarking on administration and others of whom were research workers. The course should be organized as a series of seminars. To descend to details about such a course is to expose oneself to criticism, but, since it is the purpose of this paper to provoke discussion, I end with the skeleton of a syllabus written in the context of British science.

1. The organization of science and the ways in which scientific research is administered and financed.
2. Two-way communication in science: between research workers; between scientists and technologists; between scientists and administrators; between scientists and the public; and the apparatus of criticism in science.
3. The bridges between scientific discoveries which have practical application and their successful exploitation.
4. Case studies on administration involving science. Under this head the seminar could study sets of documents of the sort which administrators have before them as the "raw material" for some major decisions involving science, e.g., a memorandum from a faculty of science to be incorporated in a university's submission to the University Grants Committee for quinquennial grants; the data from which proposals are put up to the Treasury for a quinquennial grant to cover the cost of postgraduate research studentships in Britain; memoranda from a road research station from which a brief would be prepared for a Minister on the need for expenditure on roads to reduce the accident rate.

After a study of the documents, members of the seminar would discuss the decision which was in fact taken (and various alternatives to it) and prepare their own summaries of a decision and of some of the supporting documents.

It is of course a very empirical and fragmentary way of study which I propose; but it is one which has a good deal of successful precedent in other fields. Perhaps its main value would be to give young administrators a handful of clues which they can follow for themselves, such as the clue Namier offers from the study of history: "The intense study of how things happen engenders an intuitive understanding of how things do not happen."

Science and technology are part of society and could not survive if cut off from it. Yet they are not embedded in society like organs in an organism; they are sufficiently separate from society to act on it as though from outside and to change it beyond recognition. In the newly emerging nations of Africa, we can see this transformation of society happening under our very eyes. In certain circumstances the reaction flows also in the reverse direction: science and

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technology can be profoundly influenced by social conditions. The interactions constitute a pattern past comprehension; they are numberless; they trigger off chain reactions among whole nations.

The modest objective of this essay has been to isolate a single strand from the pattern and to examine this single strand alone. If my arguments survive the discussion they are intended to provoke, they will have established these five propositions: the administrator is one of the chief channels through which science and society interact; depending on his qualifications, the administrator can promote or hinder the interaction of science and society: he can act as pump or bottleneck; no conceivable education could equip the administrator to make from his own knowledge many of the decisions he is called on to make; accordingly, his success in administration depends on (among other things) his skill in using other men's minds and in finding his way in areas of ignorance; and finally, these skills are not to be acquired through formal education alone but can be encouraged by certain kinds of instruction, examples of which are here put forward as a basis for discussion.

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ALDOUS HUXLEY

Education on the Nonverbal Level

EARLY IN THE mid-Victorian period the Reverend Thomas Binney, a Congregationalist divine, published a book with the alluring title, *Is It Possible to Make the Best of Both Worlds?* His conclusion was that perhaps it might be possible. In spite of its unorthodox message, or perhaps because of it, the book was a best seller, which only showed, said the more evangelical of Mr. Binney's Nonconformist colleagues and Anglican opponents, how inexpressibly wicked Victorian England really was.

What Mr. Binney's critics had done (and their mistake is repeated by all those who use the old phrase disapprovingly) was to equate "making the best of both worlds" with "serving two masters." It is most certainly very difficult, perhaps quite impossible, to serve Mammon and God simultaneously—to pursue the most sordid interests while aspiring to realize the highest ideals. This is obvious. Only a little less obvious, however, is the fact that it is very hard, perhaps quite impossible, to serve God while failing to make the best of both worlds—of *all* the worlds of which, as human beings, we are the inhabitants.

Man is a multiple amphibian and exists at one and the same time in a number of universes, dissimilar to the point, very nearly, of complete incompatibility. He is at once an animal and a rational intellect; a product of evolution closely related to the apes and a spirit capable of self-transcendence; a sentient being in contact with the brute data of his own nervous system and the physical environment and at the same time the creator of a home-made universe of words and other symbols, in which he lives and moves and has anything from thirty to eighty percent of his being. He is a self-conscious and self-centered ego who is also a member of a moderately gregarious species, an individualist compelled by the population explosion to live at ever closer quarters, and in ever tighter organizations, with millions of other egos as self-centered and as

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poorly socialized as himself. Neurologically, he is a lately evolved Jekyll-cortex associated with an immensely ancient brain-stem-Hyde. Physiologically, he is a creature whose endocrine system is perfectly adapted to the conditions prevailing in the lower Paleolithic, but living in a metropolis and spending eight hours a day sitting at a desk in an air-conditioned office. Psychologically, he is a highly educated product of twentieth-century civilization, chained, in a state of uneasy and hostile symbiosis, to a disturbingly dynamic unconscious, a wild phantasy and an unpredictable id—and yet capable of falling in love, writing string quartets, and having mystical experiences.

Living amphibiously in all these incommensurable worlds at once, human beings (it is hardly surprising) find themselves painfully confused, uncertain where they stand or who they really are. To provide themselves with a recognizable identity, a niche in the scheme of things that they can call "home," they will give assent to the unlikeliest dogmas, conform to the most absurd and even harmful rules of thought, feeling, and conduct, put on the most extravagant fancy dress and identify themselves with masks that bear almost no resemblance to the faces they cover. "Bovarism" (as Jules de Gaultier calls it) is the urge to pretend that one is something that in fact one is not. It is an urge that manifests itself, sometimes weakly, sometimes with overpowering strength, in all human beings, and one of the conditions of its manifestation is precisely our uncertainty about where we stand or who we are. To explore our multiple amphibiousness with a view to doing something constructive about it is a most laborious process. Our minds are congenitally lazy, and the original sin of the intellect is oversimplification. Dogmatism and bovaristic identification with a stereotype are closely related manifestations of the same kind of intellectual delinquency. "Know thyself." From time immemorial this has been the advice of all the seers and philosophers. The self that they urge us to know is not, of course, the stylized persona with which, bovaristically, we try to become identified; it is the multiple amphibian, the inhabitant of all those incompatible worlds that we must somehow learn to make the best of.

A good education may be defined as one which helps the boys and girls subjected to it to make the best of all the worlds in which, as human beings, they are compelled, willy-nilly, to live. An education that prepares them to make the best of only one of their worlds, or of only a few of them, is inadequate. This is a point on

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which, in principle, all educators have always agreed. *Mens sana in corpore sano* is an ancient educational ideal and a very good one. Unfortunately, good ideals are never enough. Unless they are accompanied by full instructions regarding the methods by which they may be realized, they are almost useless. Hell is paved with good intentions, and whole periods of history have been made hideous or grotesque by enthusiastic idealists who failed to elaborate the means whereby their lofty aspirations might be effectively, and above all harmlessly, implemented.

Just how good is modern education? How successful is it in helping young people to make the best of all the worlds which, as multiple amphibians, they have to live in? In a center of advanced scientific and technical study this question gets asked inevitably in terms of what may be called the paradox of specialization. In science and technology specialization is unavoidable and indeed absolutely necessary. But training for this unavoidable and necessary specialization does nothing to help young amphibians to make the best of their many worlds. Indeed, it pretty obviously prevents them from doing anything of the kind. What then is to be done? At the Massachusetts Institute of Technology and in other schools where similar problems have arisen, the answer to this question has found expression in a renewed interest in the humanities. Excessive scientific specialization is tempered by courses in philosophy, history, literature, and social studies. All this is excellent so far as it goes. But does it go far enough? Do courses in the humanities provide a sufficient antidote for excessive scientific and technical specialization? Do they, in the terminology we have been using, help young multiple amphibians to make the best of a substantially greater number of their worlds?

Science is the reduction of the bewildering diversity of unique events to manageable uniformity within one of a number of symbol systems, and technology is the art of using these symbol systems so as to control and organize unique events. Scientific observation is always a viewing of things through the refracting medium of a symbol system, and technological praxis is always the handling of things in ways that some symbol system has dictated. Education in science and technology is essentially education on the symbolic level.

Turning to the humanities, what do we find? Courses in philosophy, literature, history, and social studies are exclusively verbal. Observation of and experimentation with nonverbal events have no

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place in these fields. Training in the sciences is largely on the symbolic level; training in the liberal arts is wholly and all the time on that level. When courses in the humanities are used as the only antidote to too much science and technology, excessive specialization in one kind of symbolic education is being tempered by excessive specialization in another kind of symbolic education. The young amphibians are taught to make the best, not of all their worlds, but only of two varieties of the same world—the world of symbols. But this world of symbols is only one of the worlds in which human beings do their living and their learning. They also inhabit the nonsymbolic world of unconceptualized or only slightly conceptualized experience. However effective it may be on the conceptual level, an education that fails to help young amphibians to make the best of the inner and outer universes on the hither side of symbols is an inadequate education. And however much we may delight in Homer or Gibbon, however illuminating in their different ways Pareto and William Law, Hui-neng and Bertrand Russell may strike us as being, the fact remains that the reading of their works will not be of much help to us in our efforts to make the best of our worlds of unconceptualized, nonverbal experience.

And here, before I embark on a discussion of these nonverbal worlds, let me add parenthetically that even on the verbal level, where they are most at home, educators have done a good deal less than they might reasonably have been expected to do in explaining to young people the nature, the limitations, the huge potentialities for evil as well as for good, of that greatest of all human inventions, language. Children should be taught that words are indispensable but also can be fatal—the only begetters of all civilization, all science, all consistency of high purpose, all angelic goodness, and the only begetters at the same time of all superstition, all collective madness and stupidity, all worse-than-bestial diabolism, all the dismal historical succession of crimes in the name of God, King, Nation, Party, Dogma. Never before, thanks to the techniques of mass communication, have so many listeners been so completely at the mercy of so few speakers. Never have misused words—those hideously efficient tools of all the tyrants, war-mongers, persecutors, and heresy-hunters—been so widely and so disastrously influential as they are today. Generals, clergymen, advertisers, and the rulers of totalitarian states—all have good reasons for disliking the idea of universal education in the rational use of language. To the military, clerical, propagandist, and authoritarian mind such training seems

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(and rightly seems) profoundly subversive. To those who think that liberty is a good thing, and who hope that it may some day become possible for more people to realize more of their desirable potentialities in a society fit for free, fully human individuals to live in, a thorough education in the nature of language, in its uses and abuses, seems indispensable. Whether in fact the mounting pressures of overpopulation and overorganization in a world still enthusiastically dedicated to nationalistic idolatry will permit this kind of subversive linguistic education to be adopted by even the more democratic nations remains to be seen.

And now, after this brief digression, let us return to our main theme, the education of multiple amphibians on levels other than the verbal and the symbolic. "Make the body capable of doing many things," wrote Spinoza. "This will help you to perfect the mind and come to the intellectual love of God." Substitute "psychophysical organism" for "body," and you have here the summary of a program for universal education on the nonsymbolic level, supplemented by a statement of the reasons why such an education is desirable and indeed, if the child is to grow into a fully human being, absolutely necessary. The detailed curriculum for an education in what may be called the nonverbal humanities has still to be worked out. All I can do at this time is to drop a few fragmentary hints.

Two points, to begin with, must be emphatically stressed. First, education in the nonverbal humanities is not just a matter of gymnastics and football, of lessons in singing and folk dancing. All these, of course, are good, but by themselves not good enough. Such traditional methods of training young people in nonverbal skills need to be supplemented, if they are to yield their best results, by other kinds of training, beginning with a thorough training in elementary awareness. And the second point to be remembered is that education in the nonverbal humanities is a process that should be started in the kindergarten and continued through all the years of school and college—and thereafter, as self-education, throughout the rest of life.

At the end of a delightful anthology entitled *Zen Flesh, Zen Bones*, its editor, Mr. Paul Reps, has printed an English version of an ancient Tantrik text in which Shiva, in response to Parvati's questions about the nature of enlightened consciousness, gives a list of one hundred and twelve exercises in the art of being aware of inner and outer reality on its nonsymbolic levels. *Gnosce Teipsum.* But

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how? From the vast majority of our pastors and masters no answer is forthcoming. Here, for a blessed change, is a philosophical treatise that speaks of means as well as of ends, of concrete experience as well as of high abstractions. The intelligent and systematic practice of any half-dozen of these hundred and twelve exercises will take one further towards the realization of the ancient ideal of self-knowledge than all the roaring or pathetic eloquence of generations of philosophers, theologians, and moralists. (Let me add, in passing, that whereas Western philosophy tends to be concerned with the manipulation of abstract symbols for the benefit of the speculative and moralizing intellect, oriental philosophy is almost always essentially operational. "Perform such and such psychophysical operations," the exponents of this philosophy say, "and you will probably find yourself in a state of mind which, like all those who have achieved it in the past, you will regard as self-evidently and supremely valuable. In the context of this state of mind, speculation about man and the universe leads us, as it led earlier thinkers, to the metaphysical doctrine of *Tat tvam asi* [thou art That], and to its ethical corollary—universal compassion. In this philosophy it is the experiential element that is important. Its speculative superstructure is a thing of words, and words, though useful and necessary, should never be taken too seriously.")

Education in elementary awareness will have to include techniques for improving awareness of internal events and techniques for improving awareness of external events as these are revealed by our organs of sense. In his introductions to several of F. M. Alexander's books, John Dewey insisted upon the importance of a properly directed training in the awareness of internal events. It was Dewey's opinion that the training methods developed by Alexander were to education what education is to life in general—an indispensable condition for any kind of improvement. Dewey had himself undergone this training and so knew what he was talking about. And yet in spite of this high praise bestowed by one of the most influential of modern philosophers and educational reformers, Alexander's methods have been ignored, and schoolchildren still receive no training in the kind of internal awareness that can lead to what Alexander described as "creative conscious control."

The educational and therapeutic values of training aimed at heightening awareness of internal events was empirically demonstrated during the first quarter of the present century by the eminently successful Swiss psychiatrist, Dr. Roger Vittoz. And in recent

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years methods similar to those of Vittoz and to the Tantrik exercises attributed many centuries ago to Shiva have been developed and successfully used both in the treatment of neurotics and for the enrichment of the lives of the normal by the authors of *Gestalt Therapy,* Drs. Frederick F. Perls, Ralph F. Hefferline, and Paul Goodman.

All our mental processes depend upon perception. Inadequate perceiving results in poor thinking, inappropriate feeling, diminished interest in and enjoyment of life. Systematic training of perception should be an essential element in all education.

Our amphibiousness is clearly illustrated in the two modes of our awareness of external events. There is a receptive, more or less unconceptualized, aesthetic and "spiritual" mode of perceiving; and there is also a highly conceptualized, stereotyped, utilitarian, and even scientific mode. In his *Expostulation and Reply* and *The Tables Turned,* Wordsworth has perfectly described these two modes of awareness and has assigned to each its special significance and value for the human being who aspires to make the best of both worlds and so, by teaching his psychophysical organism to "do many things," to "perfect the mind and come to the intellectual love of God."

"Why, William, on that old grey stone,
Thus for the length of half a day,
Why, William, sit you thus alone,
And dream your time away?

Where are your books?—that light bequeathed
To beings else forlorn and blind?
Up! Up! and drink the spirit breathed
From dead men to their kind.

You look round on your Mother Earth,
As if she for no purpose bore you;
As if you were her first-born birth,
And none had lived before you."

One morning thus, by Esthwaite lake,
When life was sweet, I knew not why,
To me my good friend Matthew spake,
And thus I made reply.

"The eye it cannot choose but see;
We cannot bid the ear be still;
Our bodies feel, where'er they be,
Against or with our will.

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Nor less I deem that there are Powers
Which of themselves our minds impress;
That we can feed this mind of ours
In a wise passiveness.

Think you, 'mid all this mighty sum
Of things for ever speaking,
That nothing of itself will come,
But we must still be seeking?

Then ask not wherefore, here, alone,
Conversing as I may,
I sit upon this old grey stone
And dream my time away."

In *The Tables Turned* it is the poet who takes the offensive against his studious friend. "Up! up! my Friend," he calls, "and quit your books." And then, "Books!" he continues impatiently.

"Books! 'tis a dull and endless strife;
Come, hear the woodland linnet;
How sweet his music! on my life,
There's more of wisdom in it.

And hark how blithe the throstle sings!
He too is no mean preacher.
Come forth into the light of things,
Let Nature be your teacher.

One impulse from a vernal wood
May teach you more of man,
Of moral evil and of good
Than all the sages can.

Sweet is the lore which Nature brings;
Our meddling intellect
Mis-shapes the beauteous forms of things—
We murder to dissect.

Enough of Science and of Art;
Close up those barren leaves;
Come forth and bring with you a heart
That watches and receives.

Matthew and William—two aspects of the multiple amphibian that was Wordsworth, that is each one of us. To be fully human, we must learn to make the best of William's world as well as of Matthew's. Matthew's is the world of books, of the social heredity of

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steadily accumulating knowledge, of science and technics and business, of words and the stock of second-hand notions which we project upon external reality as a frame of reference, in terms of which we may explain, to our own satisfaction, the enigma, moment by moment, of ongoing existence. Over against it stands William's world—the world of sheer mystery, the world as an endless succession of unique events, the world as we perceive it in a state of alert receptiveness with no thought of explaining it, using it, exploiting it for our biological or cultural purposes. As things now stand, we teach young people to make the best only of Matthew's world of familiar words, accepted notions, and useful techniques. We temper a too exclusive concentration on scientific symbols, not with a training in the art of what William calls "wise passiveness," not with lessons in watching and receiving, but with the injunction to concentrate on philosophical and sociological symbols, to read the books that are reputed to contain a high concentration of "the spirit breathed from dead men to their kind." (Alas, dead men do not always breathe a spirit; quite often they merely emit a bad smell.)

It is related in one of the Sutras that on a certain occasion the Buddha preached a wordless sermon to his disciples. Instead of saying anything, he picked a flower and held it up for them to look at. The disciples gaped uncomprehendingly. Only Mahakasyapa understood what the Tathagata was driving at, and all that he did was to smile. Gautama smiled back at him, and when the wordless sermon was over, he made a little speech for the benefit of those who had failed to comprehend his silence. "This treasure of the unquestionable teaching, this Mind of Nirvana, this true form that is without forms, this most subtle Dharma beyond words, this instruction that is to be given and received outside the pale of all doctrines—this I have now handed on to Mahakasyapa." Perceived not as a botanical specimen, not as the analyzed and labeled illustration of a pre-existent symbol system, but as a nameless, unique event, in which all the beauty and the mystery of existence are manifest, a flower can become the means to enlightenment. And what is true of a flower is true, needless to say, of any other event in the inner or outer world—from a toothache to Mount Everest, from a tapeworm to The Well-Tempered Clavichord—to which we choose to pay attention in a state of wise passiveness. And wise passiveness is the condition not only of spiritual insight. ("In prayer," wrote St. Jeanne Chantal, "I always want to *do* something, wherein I do very wrong. . . . By wishing to accomplish something

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myself, I spoil it all.") In another context, wise passiveness, followed in due course by wise hard work, is the condition of creativity. We do not fabricate our best ideas; they "occur to us," they "come into our heads." Colloquial speech reminds us that, unless we give our subliminal mind a chance, we shall get nowhere. And it is by allowing ourselves at frequent intervals to be wisely passive that we can most effectively help the subliminal mind to do its work. The *cogito* of Descartes should be emended, said Von Baader, to *cogitor*. In order to actualize our potentialities, in order to become fully human and completely ourselves, we must not merely think; we must also permit ourselves to be thought. In Gardner Murphy's words, "Both the historical record of creative thought and the laboratory report of its appearance today, indicate clearly that creative intelligence can spring from the mind that is not strained to its highest pitch, but is utterly at ease." Watching and receiving in a state of perfect ease or wise passiveness is an art which can be cultivated and should be taught on every educational level from the most elementary to the most advanced.

Creativity and spiritual insight—these are the highest rewards of wise passiveness. But those who know how to watch and receive are rewarded in other and hardly less important ways. Receptivity can be a source of innocent and completely harmless happiness. A man or woman who knows how to make the best of both worlds—the world revealed by wise passiveness and the world created by wise activity—tends to find life enjoyable and interesting. Ours is a civilization in which vast numbers of children and adults are so chronically bored that they have to resort during their leisure hours to a regimen of non-stop distractions. Any method which promises to make life seem enjoyable and the commonplaces of everyday experience more interesting should be welcomed as a major contribution to culture and morality.

In *Modern Painters* there is a remarkable chapter on "the Open Sky"—a chapter which even by those who find Ruskin's theology absurd and his aesthetics frequently perverse may still be read with profit and admiring pleasure. "It is a strange thing," Ruskin writes, "how little in general people know about the sky. It is the part of creation in which nature has done more for the sake of pleasing man, more for the sake and evident purpose of talking to him and teaching him, than in any of her works, and it is just the part in which we least attend to her. . . . There is not a moment in any day of our lives in which nature is not producing (in the sky) scene after

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scene, picture after picture, glory after glory, and working always upon such exquisite and constant principles of the most perfect beauty, that it is quite certain it is all done for us and intended for our perpetual pleasure." But, in point of fact, does the sky produce in most people the perpetual pleasure which its beauty is so eminently capable of giving? The answer, of course, is No. "We never attend to it, we never make it a subject of thought. . . . We look upon it . . . only as a succession of monotonous and meaningless accidents, too common or too vain to be worthy of a moment of watchfulness or a glance of admiration. . . . Who, among the chattering crowd, can tell me of the forms and the precipices of the chain of tall white mountains that girded the horizon at noon yesterday? Who saw the narrow sunbeam that came out of the south and smote their summits until they melted and mouldered away in a dust of blue rain? . . . . All has passed unregretted as unseen; or if the apathy be ever shaken off, if even for an instant, it is only by what is gross or what is extraordinary." A habit of wise passiveness in relation to the everyday drama of the clouds and mist and sunshine can become a source, as Ruskin insists, of endless pleasure. But most of the products of our educational system prefer Westerns and alcohol.

In the art of watching and receiving Ruskin was self-educated. But there seems to be no reason why children should not be taught that wise passiveness which gave this victim of a traumatic childhood so much pleasure and kept him, in spite of everything, reasonably sane for the greater part of a long and productive life. A training in watching and receiving will not turn every child into a great stylist but, within the limits imposed by constitution, temperament, and the circumambient culture, it will make him more sensitive, more intelligent, more capable of innocent enjoyment and, in consequence, more virtuous and more useful to society.

In the United States life, liberty, and the pursuit of happiness are constitutionally guaranteed. But if life hardly seems worth living, if liberty is used for subhuman purposes, if the pursuers of happiness know nothing about the nature of their quarry or the elementary techniques of hunting, these constitutional rights will not be very meaningful. An education in that wise passiveness recommended by the saints and the poets, by all who have lived fully and worked creatively, might help us to transform the paper promises of a democratic constitution into concrete contemporary fact.

Let us now consider very briefly two other areas in which an

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education in the art of making the best of all our seemingly incommensurable worlds would certainly be helpful and might also turn out to be practicable within the system now prevailing in our schools and colleges. It is a matter of observable fact that all of us inhabit a world of phantasy as well as a world of first-order experience and a world of words and concepts. In most children and in some adults this world of phantasy is astonishingly vivid. These people are the visualizers of Galton's classical dichotomy. For them the world presented to their consciousness by their story-telling, image-making phantasy is as real as, sometimes more real than, the given world of sense impressions and the projected world of words and explanatory concepts. Even in nonvisualizers the world of phantasy, though somewhat shadowy, is still real enough to be retreated into or shrunk from, tormented by or voluptuously enjoyed. The mentally ill are the victims of their phantasy, and even more or less normal people find themselves tempted into folly, or inhibited from behaving as they know they ought to behave, by what goes on in the superreal but unrealistic world of their imagination. How can we make the best of this odd, alien, almost autonomous universe that we carry about with us inside our skulls?

The question has been partially answered by the apostles of those numerous religious movements stemming from "New Thought." Using a vaguely theological language and interpreting the Bible to suit themselves, they have given a religious form to a number of useful and practical methods for harnessing imagination and its suggestive power in the service of individual well-being and social stability. For about a quarter or perhaps a third of the population their methods work remarkably well. This is an important fact, of which professional educators should take notice and from whose implications they should not be ashamed to learn. Unfortunately, men and women in high academic positions tend to be intellectually snobbish. They turn up their noses at the nonscientific, distressingly "inspirational" but still astute and experienced psychologists of the modern heretical churches. This is deplorable. Truth lives, proverbially, at the bottom of a well, and wells are often muddy. No genuinely scientific investigator has any right to be squeamish about anything.

And here is another truth-containing well abhorred by academic scientists of the stricter sort. Excellent techniques for teaching children and adults to make the best of the chaotic world of their phantasy have been worked out by the Dianeticists and their suc-

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cessors, the Scientologists. Their Imagination Games deserve to be incorporated into every curriculum. Boys and girls, and even grown men and women, find these games amusing and, what is more important, helpful. Made the worst of, our imagination will destroy us; made the best of, it can be used to break up long-established habits of undesirable feeling, to dissipate obsessive fears, to provide symbolic outlets for anger and fictional amends for real frustrations.

In the course of the last three thousand years how many sermons have been preached, how many homilies delivered and commands roared out, how many promises of heaven and threats of hell-fire solemnly pronounced, how many good-conduct prizes awarded and how many childish buttocks lacerated with whips and canes? And what has been the result of all this incalculable sum of moralistic words, and of the rewards and savage punishments by which the verbiage has been accompanied? The result has been history—the successive generations of human beings comporting themselves virtuously and rationally enough for the race to survive, but badly enough and madly enough for it to be unceasingly in trouble. Can we do better in the future than we are doing today, or than our fathers did in the past? Can we develop methods more effective than pious talk and Pavlovian conditioning?

For an answer to these questions—or at least for some hints as to the nature of a possible answer—we must turn to history and anthropology. Like many primitive societies today, many highly civilized societies of the past provided their members with realistically amphibious methods for dealing with negative emotions and the instinctive drives that are incompatible with communal living. In these societies morality and rational behavior were not merely preached and rewarded; they were made easier by the provision of religiously sanctioned safety valves, through which the angry, the frustrated, and the anxiously neurotic could release their aggressive or self-destructive tendencies in a satisfyingly violent and yet harmless and socially acceptable way. In Ancient Greece, for example, the orgies of Dionysus and, at a somewhat later date, the Corybantic dances, sacred to the Great Mother, were safety valves through which rage and resentment found an innocuous outlet, while the paralyzing inhibitions of anxiety were swept away in a wild rush of nervous, muscular, and hormonal activity. In this ethical and therapeutic context Dionysus was known as Lusios, the Liberator. His orgies delivered the participants from the dismal necessity of running amok, or retreating into catatonia, or stoically bottling up their

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feelings and so giving themselves a psychosomatic illness. Corybantic dancing was regarded as a form of medical treatment and at the same time as a religious rite, cathartic to the soul no less than to the adrenalin-charged body. Which did most for morality and rational behavior—the dialogues of Plato or the orgies of Dionysus, Aristotle's *Ethics* or the Corybantic dances? My guess is that, in this competition, Lusios and the Great Mother would be found to have won hands down.

In a society like ours it would doubtless be impracticable to revive Maenadism or the congregational antics of the Dionysian orgies. But the problem of what multiple amphibians should do about their frustrations and their tendencies to aggression remains acute and still unsolved. Sixty years ago William James wrote an essay entitled *The Moral Equivalent of War.* It is an excellent essay as far as it goes; but it does not, unfortunately, go far enough. Moral equivalents must be found not only for war but also for delinquency, family squabbles, bullying, puritanical censoriousness, and all the assorted beastliness of daily life. Preaching and conditioning will never of themselves solve these problems. It is obvious that we must take a hint from the Greeks and provide ourselves with physical safety valves for reducing the pressure of our negative emotions. No ethical system which fails to provide such physical safety valves, and which fails to teach children and their elders how to use them, is likely to be effective. It will be the business of psychologists, physiologists, and sociologists to devise acceptable safety valves, of moralists and clergymen to provide rationalizations in terms of the local value systems and theologies, and for educators to find a place in the curriculum for courses in the indispensable art of letting off steam.

And there is another art that merits the educator's closest attention—the art of controlling physical pain. Pain, as recent studies have made abundantly clear, is not simply a mechanical affair of peripheral receptors and special centers in the brain, and its intensity is not directly proportional to the extent of the injury which is its cause. Pain may be aggravated or inhibited by numerous psychological and even cultural factors. Which means, of course, that to some extent at least pain is controllable. This fact, needless to say, has been known from time immemorial, and for the last century and a half (from the days of Elliotson and Esdaile) has been systematically exploited in hypnotic anesthesia. Neurological research is now discovering the organic and functional reasons for these old obser-

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vations and empirical practices; a somewhat disreputable "wild" phenomenon is in process of being turned into a domesticated scientific fact, consonant with other well-known facts and safely caged within a familiar symbol-system. Taking advantage of the newfound respectability of hypnosis and suggestion, educators should now include elementary pain control in the curriculum of physical training. Control of pain through suggestion and autosuggestion is an art which, as every good dentist knows, can be learned by most children with the greatest of ease. Along with singing and calisthenics, it should be taught to every little boy and little girl who can learn it.

Training in a closely similar art may prove to be very useful as a part of ethical education. In his book *Auto-Conditioning* Professor Hornell Hart has outlined simple and thoroughly practical methods for changing moods, intensifying motivations, and implementing good intentions. There are no educational panaceas, no techniques that work perfectly in every case. But if autoconditioning produces good results in only twenty or thirty percent of those who have been instructed in the art, it deserves to take its place in every educator's armamentarium.

That we are multiple amphibians is self-evident, and the corollary of this self-evident truth is that we must attack our problems on every front where they arise—on the mental front and on the physiological front, on the front of concepts and symbols and on the front of wordless experience, on the rational front and on the irrational front, the individual front and the social front. But what should be our strategy? How are we to learn and successfully practice the art of attacking on all the fronts simultaneously? Many valuable discoveries were made by the amphibians of earlier times and alien cultures, and many discoveries are being made within our own culture today. These empirical findings of the past and the present should be studied, tested, related to the best scientific knowledge now available, and finally adapted for practical use within our educational systems. Ten million dollars from the coffers of one of the great foundations would pay for the necessary research and large-scale experimentation. Out of such research and experimentation might come, within a few years, a radical improvement in the methods currently used to prepare young people to meet the challenges of their manifold amphibiousness and to make the best of all the strangely assorted worlds in which, as human beings, they are predestined to live.

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LAWRENCE S. KUBIE

The Fostering of Creative Scientific Productivity

SCIENTIFIC TRAINING is costly. It is costly to the schools because each individual student means a large investment of teaching personnel, laboratory space, equipment and supplies, plus technical and janitor services. It is costly to the student in terms of money, time, and heartache. Furthermore, when any student either fails or changes his mind and drops out, he suffers a loss himself; but he also constitutes a loss to science of a potential scientist, the loss of all that has been invested in him, and the loss of a man who was refused admission in favor of the student who subsequently fails or drops out. Consequently, scientific schools screen their applicants rigorously and put them through the progressively finer screen of an exacting curriculum. This should yield a high percentage of creative and productive graduates. Yet it is not the experience of our best schools, who agree that the results are extremely disappointing. This phenomenon requires investigation.

Any such study must start with an effort to determine the distribution of latent potential creativity, not in terms of its ultimate fate, but in terms of its distribution in the whole population, its distribution among the applicants to scientific schools who are rejected, and also among those who are accepted and fail, as well as among those who are accepted and survive to succeed in varying ways and degrees.

This inquiry would lead to a second series of essential questions. What are the processes by which a latent scientific potential becomes manifest, and what are the processes by which it can be blocked, inhibited, driven underground and distorted? Between these two groups of processes there should be recognizable differences: and if we are to understand what happens to our efforts to train creative scientists, the extreme poles must be studied as a

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means to the understanding of intermediate shades. Furthermore, any study of the pitfalls and successes in training for scientific creativity must include a scrutiny of faculty as well as students.

The Challenge from Educators in Science

No one knows as yet how widely and evenly distributed latent creative potential is in the population as a whole. We know only that, given a certain opportunity and a certain concatenation of internal and external forces, a certain number of students "survive" the rigors of our techniques of selection and of education. Unhappily, we also know that the ability to "survive" does not correlate closely with the ability to produce creatively later. We know rather that the creative capacity of many is destroyed, only a few survivors retaining their creative zest and skill. The psychosocial, economic, familial, educational and neurotic forces which influence this outcome have never been studied. These are the basic facts about which precise data are needed.

In such a study, contrasting groups of graduate and undergraduate students and also of members of a faculty must be carefully assembled. One might, for instance, make contrasting studies of students who as applicants had seemed to show great promise and later fulfilled these expectations; of equally promising students who failed to live up to these expectations; of other students who had marginal scores on all admissions tests but who exceeded what had been anticipated; and of students who promised little and whose later performance was at the low expected level. With adequate tact, similar groups can be formed from the faculty. (Details of this sampling process are described elsewhere.[1])

Such a study would also require the development of new methods for assaying the presence of latent creative talent. Obviously, this cannot be done by correlating early scores with later fruition. One would be justified in assuming that a highly creative student or scientist must have had a high creative potential; but it would be fallacious to assume that the failure to produce creatively indicated an absence of any latent creative potential. This would beg the very question we are trying to explore. An accurate estimation of the prevalence of creative potential in the population as a whole must be independent of final productivity. It would be the starting point for subsequent studies of the extent to which educational methods and psychosocial and psychoneurotic variables determine the emer-

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gence of creative scientific work in the population.

This is not an academic issue. At their invitation I have conferred about this problem with departmental and administrative heads in various institutions for research and training in different fields of science. Both the student bodies and the faculties of these institutions were carefully screened before coming to these institutions, and also thereafter through a progressively finer mesh. Yet with remarkable unanimity all the informants agreed that in spite of this screening there are startling discrepancies between the expectations aroused by the performance of individuals during admissions procedures and their effective creative productivity in the later stages of their careers.

They describe students who have a high absorptive capacity and who are always able to reproduce learned material with facility and fidelity, but who never become creative. There are others with remarkable earlier scholastic records and outstanding scores on all admissions tests, who nevertheless perform badly either all through their scientific training, or at recurring critical points. They describe others whose performances on early examinations were low, but who prove in the end to be highly creative. There are some who actually fail examinations and yet are productive. (Among these Pasteur is one of the illustrious examples.) Thus there are students who live either up to or down to the predictive expectations which their early tests and performances aroused. There are also irregular profiles of persons whose performances in different yet related fields show wide discrepancies. Moreover, there is general agreement that these disappointing discrepancies occur so frequently that the productivity of the group as a whole is far below what one would be justified in expecting from such concentrations of high intellectual power.

Some schools emphasize the fact that similar generalizations seem to hold true for members of the faculty; namely, that productivity in earlier years or in previous academic posts does not provide a consistent or dependable index of subsequent creative productivity. Even at these upper levels there are men who fail to maintain high early productivity and men of relatively lower early performance who become unexpectedly productive with added years.

These generalizations are based on impressions rather than on precise measurements: yet they challenge us to consider whether we can develop methods by which the consistency of the predictive values of early tests and of early performance can be increased. To

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this end it is essential first to ascertain the reasons for such discrepancies by studying adequate samples of these various kinds of discrepancies and by comparing them with other samples with no such discrepancies. This requires a microscopic study of individuals who represent each of these "clinical" groups, beginning with examples of the more flagrant discrepancies. It is my thesis that such studies would soon focus on the role of masked neurotic processes in producing such discrepancies.

The Masked Neurotic Process

Let me make clear what is meant by the term "masked neurotic process." The existence of overt neuroses can be recognized easily. Indeed, the sufferer usually diagnoses himself by describing his own depressions, anxieties, compulsions, phobias, etc. Such overt symptoms tend in general to be isolated from other aspects of human life. They are self-segregating. Neurotic symptoms of this order are usually painful to the patient; but with certain exceptions they tend to spare other aspects of a man's life rather than to impair it. On the other hand there are universal but masked neurotic processes which have no outlet other than the ways in which a man lives, loves, works, and plays. Even if the patient wants to tell about them, he cannot do so because he is rarely aware of them or of their influence. Therefore he cannot describe them spontaneously, as he could any overt neurotic symptoms. Consequently, their presence is difficult to demonstrate. Nor are they revealed in any single episode in a man's life. They are recognizable only through stereotyped but concealed repetitions.

For this reason, a man's detailed history constitutes the essential basis of any study of the role of the neurotic process in scientific study and creativity. To recognize that the same type of event has happened over and over again in any person's life, in spite of his efforts *not* to repeat and in spite of changes in external circumstances, requires a detailed study of the whole course of that life. Only by gathering such details on the life histories of many students of science and of many scientists will it be possible to recognize where and how neurotogenic processes repeatedly distort or block creativity. This takes a great deal of time, the fostering of a specially confidential relationship between the subject of the study and the interviewer, and sometimes a special kind of environment. If we are to study the role in science of the hidden neurotic components in

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human nature, we must give this our full attention; and we should not be discouraged if we find that it will require the development of special centers in which such studies can be carried on under controlled and standardized circumstances, much as the O.S.S. developed its selection methods during the war.[2]

Subsequently, if we are going to apply any new knowledge to admissions procedures, we will have to develop re-enforced and highly trained admissions teams. These in turn will develop new admissions procedures, on the basis of which they will venture to make predictions on some appropriate rating scale as to the kind, quality, and amount of future creative productivity of each student, undergraduate and graduate, and each new faculty appointment. Once these predictions are corrected and validated, they will give rise to new predictive tests. It is not unreasonable to hope for such future developments.

Illustrative Clinical Examples

Let me give a few examples of the kinds of clinical histories I have in mind. There are for instance those who produce brilliantly almost up to the point of graduation (or of receiving their doctoral degrees) and then collapse. There are also the flash-in-the-pan investigators who turn out one or two creative achievements early in their careers, but thereafter become so paralyzed by their hitherto masked inner problems that they are never productive again. (For various paradoxical reasons, it can be the first taste of success which triggers off this collapse.) There are others who seem to acquire creative freedom only slowly and relatively late in life, as they gather the courage needed for that free use of preconscious processing on which creativity depends.[3] From earlier studies it appears to be true in general that this freedom has to wait upon the resolution of pre-existing emotional conflicts and problems, which may manifest themselves in many paradoxical ways.

Then, there are those who up to a point are consistently and repeatedly successful and productive, but who, either because of or in spite of this, become increasingly despondent and dissatisfied. Others who are relatively unproductive seem content almost to the point of complacency. Some young scientists will cease their productive careers after marriage. For others, precisely the reverse is true. There are productive men who go through long periods in which they are totally barren. For some these prove to be enriching

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periods of lying fallow. For others they are catastrophic years from which their creative talents never recover. For Mark Twain one such period lasted for ten desperate and nearly suicidal years after the death of his daughter, from which he was released only when he wrote *The Mysterious Stranger*.[4] For Beethoven this occurred repeatedly with the waxing and waning of his psychopathy.[5] The effects of such periods depend not only on many subtle personality factors but also on the age, emotional maturity, and level of development of the sufferer from such a blocked period. The scientist and the student of science is surely not immune to what happens to his creative counterparts in other fields.

There is the overdrive of those who are slaves to an insatiable work need. This may be experienced subjectively as a hunger for knowledge; yet it can actually be as compulsive as is the more familiar symptom of compulsive eating, with its roots not in the body's recurring need for foodstuffs but in unconscious symbolic conflicts and processes. Furthermore, it is well known that compulsive eating can turn suddenly into a total refusal of food. Similarly, when the drive for knowledge is rooted in unconscious symbolic implications, it can turn almost overnight into an equally obstinate inhibition. Actually, this reversal occurs frequently and at every level under the eyes of all educators. Yet, especially at the higher levels, it is almost wholly neglected; and the well-motivated student who suddenly becomes totally blocked is rarely given the therapeutic help he urgently needs. Yet this early neurotogenic block in learning is frequently parallelled by later neurotogenic blocks in scientific creativity.

Because we tend to neglect this phenomenon, I will re-emphasize the fact that such a reversal occurs whenever the hunger for new knowledge has been taken over by predominantly neurotic mechanisms. Therefore, it is important to study also the release from paralyzing depressions which can occur with equal suddenness and with dramatic increase in the effective use of creative potential. Between the extreme poles of compulsive overdrive and phobic inhibition, every intergrade occurs; but only the study of the pathological extremes can throw light on these milder manifestations, which are miscalled "normal" merely because they are more frequent.

This phenomenon has general human importance because the entire course of a student's life may be determined by the age at which the change from overdrive to inhibition occurs (or the change

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in the reverse direction from inhibition to release and even to overdrive). The shift may happen in primary grades, grammar school, high school, college, or graduate years; it may be triggered by a change in grades, teachers, or schools, or from a coeducational to a mono-educational environment or the reverse, or by the first experience of being away from home at school or college. Many early depressions which go unrecognized are precipitated by such changes as these, and they account for some sudden slumps in work. Many youths who seem to be daydreamers are actually suffering from masked depressions of this nature. Furthermore, such emotional changes may continue to be unrecognized, even when they occur during the higher reaches of post-postgraduate training, or even later in the career of a fully trained and previously productive and creative scientist. How often these changes occur, and how often they go unrecognized are questions whose answers are of basic importance to any over-all training program.

When a work block of any origin occurs early and lasts for any length of time, it may impede the development of even the most gifted youngster. The experience may be so painful that he may never be able to return to science. It may close all future academic doors to him. If it occurs later in the career of a productive young scientist, it can turn a promising career into a wasteland for the rest of his life. If it happens still later in the career of a man who has already won his spurs, the consequences may vary widely. Not infrequently it stops a great scientist in his tracks, whereupon he may save himself from the hell of scientific oblivion only by escaping into teaching, into administrative posts, into foundations, or even into college presidencies. This in turn can create a destructive chain reaction of secondary consequences for educational and research institutions.

For instance, the outstanding figure in a certain field gradually became scientifically sterile after he had become a full professor and departmental head. This sterility so embittered him that, although he was a passionately dedicated teacher, he could never allow any student to become creative, to publish, or even to escape from him without a fight. Furthermore, he recommended for important posts only those who were shaped in his own image and were similarly sterile. Thus his neurosis had a destructive impact on his whole field. Since the activities of all productive and creative people are vulnerable to such neurotogenic distortions, this type of problem has wide significance. Perhaps we should ask ourselves

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whether it may not be for this very reason that we educators have refused to look at it. To most of us it may come too close for comfort.

Let me give a few other simple examples. Among many possible criteria of creativity, the promptness with which work is done is frequently emphasized. But what of the man whose anxieties compel him always to rush, always to be ahead of time, the man who gets to every train not only on time but ahead of time? He parallels the student or investigator or lecturer whose work is always done longer ahead of time than necessary. In his hurry he can never stop to think, to read, to digest, to lie fallow. His opposite number is equally important: the man who gets to the train only as it is pulling out of the station, the student who barely gets his themes in on time or consistently brings them late. He can never think about a problem (much less work on it) until he is under last-moment pressure. Neither the rusher nor the dawdler can lie fallow. Neither can allow his associative processes to drift idly. What chance has either for that free-wheeling play of preconscious processing which is essential for all creativity? These patterns of compulsive rushing and obsessional dawdling are observable in kindergartens, and also throughout all schooling up to the creative years. They can exercise a crippling influence on all processes of study, of creative experimentation, and of creativity in any form. What is more, the same individual scientist can change from one form of compulsion to the other.

These examples illustrate various ways in which neurotogenic processes can take over and distort the life work of the scholar and scientist. To study this phenomenon it would be necessary to determine for each individual under what economic, social, and familial circumstances, and in what types of schools, the drive for knowledge first manifested itself, under what special influences it acquired momentum, when and how the healthy drive first seemed to become compulsively overdriven (rigid, stereotyped, and marked by obligatory repetitions), and how and when it then began to collapse. The effort would be to determine precisely when the transformation of a normal work drive into a neurotogenic overdrive occurred, when this overdrive was transformed into a work block, or alternatively whether the obsessional work block was the initial manifestation of the impact of the neurotogenic process. The full natural history of the neurotic process would also include a study of how such shifts were interrelated with disturbances in all instinctual functions and in their various intellectual and cultural derivatives.

A third variable adds still another dimension to the problem.

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Every scientific hypothesis, indeed, every scientific experiment, carries the implication of a prediction. But scientists vary in the clarity, precision, and courage with which they venture to commit themselves by making explicit the predictions which are always implicit in their work. To venture a prediction exposes one to being proved either right or wrong. In the hidden fantasies of many men this is equivalent to being shown up either as a man who masquerades as a woman or vice versa. This equivalence is linked to the fact that many human beings harbor hidden hermaphroditic fantasies of which they are largely unaware, yet which may express themselves not only in the clandestine fascination exercised by a Christine Jorgensen but in subtler disguises such as the ways in which the challenges of scientific predictions are met or evaded. For a scientist to leave unspoken the predictions latent in his work enables him to keep hidden. Therefore, whether a scientist is able openly to declare the predictions which are implicit in his work is one index of the degree to which his creative powers operate under the influence of latent or manifest forces. Thus it is necessary to develop some way of scoring the ratios of correct to incorrect predictions among both implicit and explicit predictions.

Another indication of the emotional implications of a man's work may be found in his ability (or inability) to lie fallow without anxiety, during either successful or unsuccessful phases of his work. The degree to which he can do this will be reflected in the kind of relationships he is able to sustain with his family, his students, his colleagues and his friends, as well as in his need to work in groups or in isolation. It will be reflected also in the degree to which periods of release alternate with periods of block, and whether such swings go beyond normal limits—for example, from feelings of total futility and total ineptitude to feelings of elated overconfidence.

I have cited only a few examples of the many complex patterns which mark the disturbances and distortions which plague all creative efforts. With further study, various other constellations of traits would appear, clusters which subsequently could be used in the classifying of data into appropriate subgroups. Meanwhile, all such studies must cover the full range of this multidimensional spectrum, always selecting samples from each "band" for closer study.

Appraising Creative Productivity

As already indicated, any attempt to foster creative productivity

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would be rooted in a previous study of the distribution of latent creative potential. Only then could we begin to assay the factors which determine whether latent potentials will be realized. Such a plan assumes, however, that we are able first to identify latent talent, to measure or at least estimate its quantitative and qualitative variations, and then to measure the qualitative and quantitative variations in the products in which it is expressed. None of this is easy.

The evaluation of a man's scientific output would seem to be the less elusive part of the task. Yet it is not enough to measure his productivity by the number of his researches or papers or honors; it will also be evaluated by standards which can be almost as arbitrary and ephemeral as are fashions in dresses. Indeed, in science as in other intellectual pursuits, transitory fashions play a role which can inflate or deflate reputations without regard to ultimate values. Furthermore, the game is never over until the final score is in; and this may take years of waiting.

Who, for instance, will venture to compare the relative creative productivity of two men such as these. One spends twenty-five years in obscure and repeatedly defeated struggles before finally breaking through into a new frontier. The other spends the same twenty-five years on twenty-five or more concrete pieces of research, publishing annually another report on definitive but limited investigations, some with positive and some with negative results. From the quantitative point of view, the second man has obviously been the more productive. Yet this does not necessarily make his stature either greater or less than that of the plodding worker who spent twenty-five years to achieve a single result. The neat yearly experiments, especially those with negative results, may have proved chiefly that someone else was wrong. They themselves may not have been directly productive of new knowledge. Yet they may nonetheless have cleared the way for some other man's breakthrough. Consequently, they may have made vital contributions. Indeed, without the dedicated but unsung labors of obscure men who prove only that some clues had been misleading, any Nobel prize winner might well have failed. At any particular moment in the history of science, even great scientific intelligence and imagination may miss their goal because of the limitations of current scientific knowledge. Therefore, the intelligence, skill, and devotion of the man who clears away the errors of others, or who doggedly and skillfully pursues false clues into their ultimate blind alleys, may be as great

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as are those of the man who wins international fame. These little known and unrewarded men are the expendables of science. They are no less essential than are the few who reach their goals. Therefore, until many years had passed, it would be hard to say which of these two men had had the more profound impact on scientific knowledge.

There is also the man who says of himself that he always loses his way in experimental work yet whose critical judgment is so highly developed that he guides the work of a whole group of younger associates. (By his own confession, the late Dr. William H. Welch was such a man.[6])

Therefore, if we are to attempt to correlate any basic studies of creative potential with ultimate creative productivity, we must establish clear criteria at both ends of the equation. We must learn how to recognize and appraise the relative degrees of scientific productivity in workers whose contributions are different not only in numbers and kind but also in timing: (a) the immediate "producers"; (b) those whose work bears fruit slowly; (c) those many students (and faculty) who fail to achieve spectacular positive results but who make their contributions by the definitive precision and even the brilliance of their "failures"; and (d) those highly gifted critics who do little or no work themselves but who guide the creative work of many others. These are at least four kinds of scientific creativity which may occur in different men or in different phases in the life of one man. Profound temperamental differences may determine which type of productive activity will play the dominant role, either in special phases of a scientist's creative career or throughout his life. Here is one of many examples of how both healthy and neurotic forces may concurrently exercise a profound influence on the ways in which a man uses his latent gifts.

These differences have profound secondary effects on the lives of scientists. Any mature educational system should recognize what it means to the student and to the mature scientist to be among the expendables instead of among those who survive. But if we allow ourselves to understand these painful consequences, we must also be ready to accept their challenge. The processes by which we select and educate the scientist must include something which will enable men to experience disappointments without becoming embittered and distorted. This has a humanitarian aspect, not for humanitarian reasons alone, but for the sake of scientific progress itself. As in the example given above, the scientist who is embittered and distorted

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feeds fresh distortions back into his further creative efforts and consequently into those of his students. In this way distortion can propagate itself in future generations.

One can find many examples of such proliferation. This is why no method of estimating a creative potential which is based solely or mainly on quick positive achievements which are easily recognizable will contribute to a rounded understanding of the creative process in science, nor in the long run to our methods of choosing men or nurturing their talent. We must include the less spectacular but equally vital achievements of those who disprove the false. The unique honor of science is the humility and honesty with which it constantly corrects its own errors. It is this which makes it the greatest among the so-called humanities.

The Creative Process

Can we then characterize more precisely the creative act or process, and behind that the latent creative potential? Here I can present only an operational concept which is subject to the usual vicissitudes of trial and error. Even if creativity can be so characterized, shall we then be able to assign any quantitative value to these acts or potentials? Or must we content ourselves with the simpler judgment of "present" or "absent?"

As stated elsewhere,[7] the uncovering of new data and of new relationships among both new and old data is not the whole of creativity, but it is that addition to the mastery of established data which characterizes creativity. Thus creativity implies invention: to wit, "the making of new machines or processes by the application of old or new facts and principles, or by a combination of them in order to uncover still newer facts and newer combinations, thus to synthesize new patterns out of data whose interdependence had hitherto gone unnoted and unused."[7] Or again, "Cogitation and intelligence:" that is, "*Cogito*—shaking things up, to roll the bones of one's ideas, memories, and feelings, to make a great melting pot of experience: plus the superimposed process of *intelligo*, i.e., consciously, self-critically but retrospectively to go through an after-the-act process of choosing from among unanticipated combinations those patterns which have new significance."[7] This is what constitutes creative activity.

Here the critical psychological fact is that the recognition of new data and new relationships and the assembling of new combinations are predominantly a *preconscious* process, not the outcome

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of either unconscious processes (as is mistakenly claimed) or of conscious rumination. The former confines and restricts the play of preconscious processing. The latter samples it in a pedestrian fashion, checks and tests it, and anchors it to reality. Therefore, the impact of these two concurrent processes on the free play of preconscious processing should be the focus of every inquiry into the influence of any educational program on the creative potential of human beings. This is where we find the interplay between psychosocial processes and the ubiquitous masked neurotic processes of the so-called "normal."

This hypothesis focuses our inquiry with some precision on the freedom of preconscious processes, as these operate between the pedestrian, literal, reality-anchored restrictions of our conscious sampling processes, on the one hand, and the rigid, repetitive, stereotyped, neurotogenic limits of unconscious processes, on the other. Thus two sets of processes, the one conscious and the other unconscious, accompany our preconscious processes like a pair of bailiffs on either side of a prisoner. We must seek to develop methods to assay their concurrent roles and to establish both the degree and the areas of freedom of the creative preconscious—freedom, that is, from the pedestrian limitations imposed by conscious processing, and also freedom from the neurotic distortions imposed by unconscious processes. This will lead to an inquiry into what our educational system does about all this in the development of the student of science and also in the later creative years of the mature scientist. Although precise methods for ascertaining this effectiveness are still lacking, it may at least define our goal more clearly.

Let me repeat that we will be wise to begin the pursuit of this goal by ascertaining the facts: what actually happens to gifted young men who have been carefully screened, selected, chosen, and accepted for an exacting educational curriculum in one of our best scientific schools? What happens to them as undergraduate students of science, as graduate students, and finally as members of a scientific faculty? If we ascertain those basic facts, we can select from these groups statistically representative samples for more intensive study. This would outline a general approach that may illuminate this most important of all human educational problems.

Summary

In the higher education of scientists, we seem to be duplicating

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a mistake to which we have all become accustomed in the earlier phases of child development. It is well known that the small child has an extraordinarily free and creative imagination, which he manifests in his use of words, images, color, design, and tones, and in his general attitude to the world around him. Under the impact of many forces which operate in early life, this freely creative imagination usually disappears or at least goes underground. We know the nature of some of the destructive forces but not of all. We can recognize that some arise as a distortion of the child's own development. We know also that his spontaneous inhibitory processes are re-enforced by many cultural attitudes, by the "conspiracy of silence"[8, 1] that surrounds the problems which are most important to the child, his struggles over his lustful and destructive impulses and over his curiosity about the forbidden things about the human body and its apertures, products, functions, feelings, and sensations. Later the inhibitory processes are further re-enforced by certain ingredients in our educational system, specifically by a fetishistic emphasis on drill and grill. In the educational processes of advanced scientific training, the destructive ingredients seem even more strongly entrenched. This would appear to be why so many gifted young students of science who have been carefully screened and selected undergo a profound attrition of their creative potentials.

In the learning process, people divide into at least three groups, possibly more. There are those whom Dr. Azenath Petri would call "stimulus-bound."[9] They take in and give out promptly in response to percepts, but with little penetration into their own inner psychological processes. These are the students who listen to a lecture and produce the most precise and perfect notes, while little is going on inside them. There are others who take in and reproduce equally automatically, but then industriously and dutifully take their notes home and study them, drilling and grilling themselves as they learn in a time-honored yet pedestrian and uncreative fashion. There are others who may take in without even knowing that they are doing so, and who then proceed to process this data with enormous speed and freedom by analogic methods, and for the most part without interposing the delays which are inherent in the processes of conscious sampling. This is the so-called imageless thinking of the Wurzburg School—what we would call free associations or preconscious processing.

Why do we speak of young men as being capable of doing "hard work," as though "work" had to be hard? It has long been known

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that efficient learning is never hard, and that the degree of effort which seems to be required is never an index of the work which learning and creating involve, but is rather a measure of intrapsychic interference within the machine itself. The "hardness" of work is analogous to the heat built up in a machine—a measure of the loss of efficiency.

Not many of even the gifted and potentially creative students survive the impact of drill and grill. We do not know how many survive and how many fail. We know only that a heavy toll is paid. Those who are destroyed constitute a wastage of creative manpower, caused by a method of education which destroys creativity and the freedom of our preconscious functions. Yet this destruction is certainly not due to educational processes alone. There is an earlier process of destruction that arises out of those deep wells of unrecognized guilt and fear which hamper the free play of human imagination. These neurotogenic forces are universal but variable. They are intensified but not created by the impact of a wrongly oriented educational procedure.

Institutions dedicated to instruction in the highest levels of scientific creativity can no longer afford to shut their eyes to this challenge. Yet they must not ask for quick and easy answers. They must be ready to join in years of preliminary basic research which can be conducted on their own students and faculties only by mature, multidisciplinary teams.

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W. ARTHUR LEWIS

Education for Scientific Professions in the Poor Countries

THE POOR COUNTRIES need three types of persons trained scientifically beyond the high-school level: technicians, basic scientists, and professionals. By professionals we mean those trained in agriculture, medicine, dentistry, veterinary science, engineering, architecture, and similar arts. Such courses of education have this in common, that they borrow materials from a number of basic sciences, which they use as a foundation for specialized work. This raises a number of problems, to which this paper is devoted.

The capacity of a country to absorb university graduates is an index of its development. If we take graduates in all subjects, including the humanities, the absorptive capacity measured in terms of the annual intake of graduates seems to range from as low as 20 to as high as 3,000 per million inhabitants. Frederick H. Harbison has recently assessed the absorptive capacity of Nigeria at 50 per million; in recent guesses for the West Indies, I have been using a figure of 300 per million. The concept of absorptive capacity is not a precise one, however. As the number of graduates increases, the possession of a degree becomes a condition for jobs for which it was not previously required, for example, in agricultural extension, dentistry, or teaching in high schools. Also, the gap between the salaries of graduates and nongraduates diminishes as graduates become available for more types of jobs. In other words, the absorptive capacity increases *pari passu* with the supply of graduates and cannot be determined independently. It may still be possible to produce from historical or contemporary data a curve relating the absorption of graduates per million inhabitants to the per-capita national income, but this has not yet been done.

All one can say at present is that, in the sense there are vacant jobs, in nearly every poor country there is a shortage of persons

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trained in the scientific professions. This is all one needs to say. Most poor countries could substantially increase their output of professionals without any danger of the supply exceeding the absorptive capacity during the next two decades.

In the United States a number of universities consider that professional courses should be undertaken only after a student has already acquired a first degree. This can be defended on two grounds: the student needs to have a good general education before embarking on professional study; or he needs to know a great deal of science before embarking on a scientific profession. The first ground is emphasized, rather than the second, though the second may be included in the first.

In Great Britain the professions we are dealing with can all be studied for a first degree. Before entering the university, however, the student will usually be required to have specialized in science in the high school, as evidenced by his having passed certain science subjects (specified separately for each profession) at the Advanced Level (formerly the Higher School Certificate), equivalent to or slightly beyond what a junior college in California requires. In short, whether professional courses should be postgraduate or not depends on the university requirements for enrolling in basic science, which in turn depend on the standard reached in the high schools. The high schools in Great Britain teach two years more of science than a public high school in New York City does, and as this is the level of university entrance, professional courses may be taught as training for first degrees.

The poor countries vary widely in the standards to which their high schools aspire. In Africa the British and the French have sought to establish standards at their metropolitan levels, and, in so far as they have succeeded, most of Africa should be able to follow the British or French patterns. In some other countries (for example, Egypt or India), in which the numbers of high-school students have swollen more rapidly than funds or trained teachers have, high-school standards are lower, and both entrance and exit levels into and out of universities are substantially lower than in Western Europe. Faced with low standards of entry, the universities in such countries must either lower the professional standard or else lengthen the course (of which the extreme form is to make the professional course postgraduate).

The question as to whether there should be less basic science is a difficult problem. A number of arguments point toward reducing

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the amount of basic science in professional courses in the poor countries. The students have less practical work in their backgrounds than do the students of rich countries, and therefore they need more time for this aspect. They have less practical experience because in their societies it is offensive for a middle-class person to do manual work instead of employing a servant to do it for him. (This is a form of share-the-wealth which custom has decreed in areas that do not have social insurance.) Students also have less experience with mechanical devices, since they do not live in a mechanical civilization and therefore do not become familiar with mechanical devices from an early age, as do children in the rich countries. Consequently, more time is needed in their professional training to accustom them to using their hands.

Because technicians are not as well trained and not as reliable as in the rich countries, professionals have to spend more time supervising them; the professionals must be able to show their technicians just what to do. The professional, therefore, needs the technician's training as well as his own. This also means relatively more time for practical work. Since professionals are scarce and therefore work in greater isolation from one another, each must have more of an all-round competence. For example, an engineer sent to look after public works in an isolated rural area should be able to turn his hand to civil, mechanical, and electrical tasks; hence he must be given relatively more "know-how" of the various sides of his profession, and he has relatively less time for basic science. The same argument tells in general against providing opportunities for specialization in the undergraduate professional course. Most universities require the student to familiarize himself with every aspect of his profession (if we count civil, mechanical, and electrical engineering as three separate professions) and to postpone specialization until postgraduate courses. A medical student is not allowed to choose between pediatrics and surgery. In the rich countries, however, there are some exceptions: an agricultural student may choose between, say, chemistry and entomology, and an electrical engineer may choose between power generation and electronics. Specialization usually involves more basic science. It is arguable, therefore, that universities in the poor countries should be less willing to permit specialization at the undergraduate level.

In some professions the need of using local materials for teaching purposes increases the factual burden of the course and thus reduces the time available for theoretical principles. This situation

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occurs wherever the local material has to be an auxiliary to, not merely a substitute for, the material used in teaching in temperate countries. For example, the medical student in the tropics has to know about all the diseases that occur in temperate zones, since these also occur in the tropics, and in addition he has to know about tropical diseases. In adapting any syllabus for use in a poor country, one has to decide how much of the factual framework taught elsewhere can be scrapped in favor of local conditions and how much must be retained. In some cases the result must be a net increase in the facts to be studied.

The professional must learn more social science in the poor countries, since social change is occurring more rapidly there than in the rich countries, and therefore the professional is more deeply involved. His own work is one of the important forces causing social change. Moreover, his status in society is continuously being affected by the changes taking place. Some room, therefore, should be found in his course for instruction in the sociology of change. One cannot class this problem with other aspects of general education and dismiss it by saying, "This should be done in the high schools before the student reaches the university." Students of high-school age are not ripe for sociology.

So much for the arguments for reducing courses in basic science. A strong case can also be made for maintaining the amount of basic science taught. This argument would begin with the premise that the professional is isolated and consequently needs to be able to turn his hand to many things. To do this, he must have a sound training in basic principles rather than a superficial training in techniques. In his isolation he will meet many new problems which he can solve only by taking thought and by returning to basic principles. He needs both more science and more technique, and if one has to be sacrificed, it is not obvious that it is the science that should be curtailed.

The correct answer to our question is probably this: if the professional standard is to be as high in the poor as in the rich countries, professional courses should be a year or so longer in the poor ones, to allow for an inferior background in high schools, the need for more practical work, an increase in the syllabus because of the incorporation of local materials, and the need for a greater emphasis on social studies. But should the professional standard be as high in the poor as in the rich countries? There are several arguments for a lower standard. Even in the rich countries most professionals are

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overtrained for the work they actually have to do. University syllabuses tend to be framed with an eye on the student who will become a university teacher or research worker, whereas the great majority go into jobs they could do just as well with a year less of academic training. The poor countries need proportionately even fewer research workers, and separate provisions can be made for their training. To maintain equal standards requires a longer and correspondingly more expensive training in the poor countries, which they cannot afford. Many such nations have abandoned the attempt to maintain equal professional standards, even if they once tried to do so. Given the great shortage of professionals, especially in rural areas, such a nation is better off with four three-quarters trained professionals than with three fully trained.

Although many countries have abandoned the attempt, many others still strive to maintain their professional standards at European levels, not only out of national pride but also for other reasons. The routine portion of professionals' work is usually passed over to technicians, whose numbers can be multiplied more easily. This practice makes it all the more important that the relatively small number of professionals who supervise technicians should be thoroughly trained.

The psychological effects of inferior standards are bad. A poor country is likely to employ a number of well-trained foreign professionals, and it is embarrassing if its own professionals are admittedly of inferior quality. This is especially true when the better paid or more responsible jobs are held only by people with foreign qualifications. The local universities are downgraded in the public eye, and students try to go abroad for education rather than to their home institutions. The latter are discouraged and find it hard to recruit or keep good staffs. This further reduces their quality by adversely affecting their capacity to do useful research. For such reasons, a number of countries have abandoned the inferior professional qualifications they previously offered (for example, Nigeria has dropped medicine, and Trinidad, agriculture) and have substituted qualifications intended to equal similar qualifications in Europe.

Although the great majority of the graduates of professional schools are required for jobs that demand competence but not brilliance, a significant number are needed to undertake fundamental research. The biological sciences and the professions based on them demand much more fundamental research than do the physical sciences. Whereas the physical structure of the earth is much the same

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in temperate as in tropical zones, the living organisms differ considerably. An engineer can transfer from a temperate to a tropical environment with only small adaptations; but an agriculturist has to spend a year or more relearning his job.

How fundamental is "fundamental"? Some research requires scientific training and imagination of the highest order; in the process, new scientific truths of universal application will be discovered. In the biological sciences, it is hardly profitable to distinguish between pure science and research of the kind the poor countries need—for example, research in animal and plant genetics, leading to the breeding of new useful types; human and animal physiology in hot climates; pests and diseases, animal, plant, and human; or plant and animal nutrition. Basic principles already worked out in temperate countries will be applied, but since the animals, the plants, the insects, and the microbes are different, the research has to start almost from scratch; it demands the highest qualities, and is likely to yield new universal principles.

The situation in the physical sciences is rather different. Here the main research task is to devote known principles to making inventories of economic resources: discovering minerals or underground water supplies; assessing soils; recording river flows and meteorological data. Such work demands professional competence rather than scientific imagination. The principal scope for fundamental research is in such fields as these: climatology; methods of combating the effects of torrential rain, earthquakes, or months of continuous sunshine on such structures as roads, dams, and buildings; the utilization of local resources, such as crops, forests, building materials, sources of energy; the conversion of sea water; the invention of new engineering processes that use less capital. Some of this research (especially on the exploitation of materials) can be done in the laboratory in temperate countries, but virtually all the biological research, and nearly all that part of the physical research that is concerned with the effects of the local environment, have to be done on the spot.

There ought, therefore, to be a large number of fundamental research stations strung round the globe between the Tropics of Cancer and Capricorn. Actually, there are very few such stations. The tropics are not yet adequately equipped even to make routine inventories of their resources; and they are far from coming to grips with fundamental research. It is not necessary that each country establish a battery of high-quality research stations. For example,

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there are now twenty countries in West and Equatorial Africa between the ex-Belgian Congo and the Sahara Desert, but most of them have less than 2,000,000 inhabitants and could not support expensive research institutes. Asia fares better, having fewer and larger countries, of which several could maintain their own scientific establishments, as indeed India already does to a very considerable extent. It is true even of Southeast Asia, however, as of Africa and Latin America, that the necessary stations for fundamental research will not be established on a substantial scale until groups of countries learn to combine for this purpose, with or without the United Nations or other international assistance. There have been some good beginnings, for example, sugar-cane breeding in the West Indies, cocoa research in West Africa, or rubber research in Malaya, as well as outstanding work on tropical diseases (done mainly in the laboratories of temperate countries). Nevertheless, an immense scope for expansion remains.

Since the professionals depend on basic science, their research work depends on a supply of persons with a first-class training in science, whether educated in the professional or in the science schools. The science schools, like the professional ones, mainly produce persons who need to be competent rather than brilliant. Most of their graduates go into high-school teaching or into routine jobs in commerce or administration. There is little manufacturing industry, and such as there is generally does not engage in research or else it conducts its research in parent establishments in the rich countries. The universities themselves are the largest market for highly trained scientists capable of good research. Nevertheless, every university science school is under pressure to do some research and keep up its standards, partly to make its own teaching lively, partly to contribute to knowledge, and partly because good scientists cannot be retained unless they are given opportunities for research. Many universities are therefore able to produce some men who, given further training, would do well in research.

In the professional schools, professors interested in research tend to feel badly handicapped by not having learned enough basic science in their own undergraduate days, and this prejudices them in favor of putting more and more basic science into the undergraduate syllabus, even at the cost of lengthening the course. This is hardly necessary, since the small number of professional men who go on to research can learn the extra basic science they need during their postgraduate training.

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What seems important is that, whereas the undergraduate course can be taught adequately in a professional school that has very little basic science, postgraduate training and research in professional subjects can be done adequately only in close association with strong science schools. Thus, while undergraduate teaching can be dispersed over a number of schools, postgraduate teaching must be concentrated in a small number of institutions in which both basic science and professional study are highly developed. It is all the better if these postgraduate teaching institutions can be linked with the fundamental institutes.

Study in foreign countries has many attractions that study at home lacks. Standards are usually higher, the qualification carries more prestige, and its monetary value may exceed that conferred by the local school. Also, travel provides valuable experience. If the students go to foreign universities whose costs are met principally out of public funds and not out of student fees, it becomes much cheaper to send them abroad than to educate them at home. For example, for what it costs to run the University College of the West Indies, we could send one and a half times as many students to universities in Great Britain. This argument applies to small countries like the West Indies or Ghana, but not to large countries like India. Professional schools are especially costly to small nations, because they need a minimum complement of staff to teach each aspect of the course. For example, Nigeria has been advised that to run a veterinary school economically requires an output of about seventy students a year, and she is finding this a stumbling block. The remedy would be for countries in this situation to group together to run professional schools; but this is not always politically possible.

On the other hand, the provision of professional schools at home has several advantages which may outweigh the higher cost. In so far as the syllabus is based on local materials and on research into local problems, what the student learns in the home university is more relevant to the job he will have to do. This is particularly important in the biological professions. The teachers do not merely teach: if doctors, they look after patients, inside and outside the hospital; if engineers, they do consulting work. The teachers play a part in the life of the community, they sit on boards and participate in private and public decision-making. If they are of adequate scientific caliber, they also carry on useful research of a kind worth paying for, even if there were no students. A large proportion of students who do go abroad do not return home, and the cost of edu-

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cating them, therefore, is lost to their country, except in so far as they make remittances.

A good compromise is to give students their first degree at home and then to send the better ones away for postgraduate training in large, well-staffed and well-equipped institutes. As we have seen, however, the poor countries need a few of their own such institutes to do fundamental research into the problems of their regions. Where such institutes exist, a student can do effective postgraduate work there before he goes abroad.

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ROBERT S. MORISON

The University and Technical Assistance

THE MOST OBVIOUS difference between the developed and the underdeveloped areas of the world is that individuals in the developed parts have more to eat, warmer and better looking clothes, nicer, more commodious houses, enjoy more robust health, and can move about much more easily and quickly than do those in the underdeveloped parts. How has this state of affairs come about and what can we do about it? Of all the puzzling questions which have arisen to disturb the peace of the twentieth century, none is more fundamental than these two.

Although much of what must be said on this subject is already familiar, there remains a very real danger that many current answers are either false or dangerously incomplete. If those responsible for rectifying the present imbalance are allowed to fix their attention on inadequate interpretations of the causes of our present difficulties, it is most unlikely that they will find the proper things to do about them.

The two simplest explanations of the discrepancies between a developed and an undeveloped economy are the following: rich countries are rich because they have taken things away from the poor countries, and poor countries are poor because the people in them are stupid and do not work very hard. The first explanation is the one most widely held in the poor countries and is an established part of the Marxist interpretation of history. The second proposition was once a matter of public belief in the advanced countries but has retreated to more hidden positions. Both continue to vex official and personal relationships between the two parties, and the forces they generate continue to absorb energy which might better be expended in other directions.

Neither proposition has ever been established on the basis of

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objective evidence and there is a reasonable doubt that either can be proved or disproved even by the most precise scholarship. Too many variables are involved and too many of the variables are hidden away in historical contexts more or less irrelevant to the present situation. But there are certain obvious things that ought to be remembered before we jump to conclusions. As far as one can see, there is little correlation between the richness of a given country and the degree to which it has directed its energies to exploiting poorer countries through a colonial system. It seems doubtful if any Western nations have ever been more single-mindedly devoted to taking wealth away from other areas than were Portugal and Spain, yet today these are the poorest in Western Europe. The four other European nations which have maintained colonial empires until the present day are not demonstrably better off than a larger number which have not. It is even more absurd to maintain, as many people seriously do, that the United States owes even a slight fraction of its half-trillion-dollar gross national product to the brief period in which it controlled the affairs of Puerto Rico and the Philippines.

What about the poverty of the underdeveloped countries? It seems fairly clear that the Incas and the Aztecs were better off before the conquistadores arrived, and there has always been some doubt about the balance sheets in Bengal during the period in which Clive was astounded at his own moderation. Since that time, however, it has become increasingly difficult to prove that poor countries are poor because they have suffered a net outflow of goods and services. Africa provides a particularly interesting case, since it is very nearly true that the standard of living of the population there varies almost directly with the intensity of contact with Europe.

Vaguely uneasy over the repeated charges of exploitation and greed, the Westerner has tried to assuage his guilt by ascribing the discrepancies in living standards to differences in intelligence and industry. It must be candidly admitted that there is a certain amount of *prima facie* evidence for these notions. People brought up in relatively restricted rural environments ordinarily do not act very intelligently when confronted with an entirely different set of circumstances, and people who see no particular point in working hard do not do much work. These matters deserve to be borne in mind by those interested in hastening the development of emerging countries. It is a serious mistake, however, to jump to the conclusion that there is something innate and unchangeable about the situation. The scholastic and technical achievements of selected individuals

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who have enjoyed the still too rare opportunity for appropriate training and education show that the underdeveloped countries can produce persons with the necessary capacities and motivations to perform the tasks which complex modern industrial society requires. Indeed, one commonly hears instructors in the new African university colleges express concern that many of the students may be working too hard and too conscientiously for their own good. If neither of the current simple explanations helps us much in explaining the backwardness of underdeveloped areas, where shall we look?

The most obvious answer is that the underdeveloped countries have participated only in varying degrees of incompleteness in the process of social and scientific invention which began in Europe about five hundred years ago. Up to that time grinding poverty was the lot of ordinary men everywhere and it remained so during at least the first half of this evolutionary period, even in Europe. In other words, roughly half the time necessary to develop the presently advanced countries was taken up with laying the basic groundwork of social ideas and scientific concepts on which the industrial revolution was built. During this period the ordinary man could detect very little increase in the amount of food and shelter and other good things available to him. Perhaps the best evidence for the relatively static nature of man's material welfare in this period is the very small rate of change in the growth of populations before the eighteenth century.

These matters seem worth reviewing, though necessarily somewhat briefly, if only to reassure ourselves about the size of the gap we are talking about. Measured in terms of food, shelter, automobiles, illiteracy rates and mortality figures, it is staggeringly large. In terms of *time*, it is surprisingly small. Even if we date the beginning of civilization as late as the invention of the alphabet (approximately 4,000 years ago), it turns out that a country like India is only about six or seven percent behind the United States in its development. Yet even this figure may be high, since in many ways India is already well ahead of where Europe and the United States were in 1750. From one point of view, its rise in population is a legitimate source of worry; yet it testifies to the fact that the food supply is no less adequate than in most of Europe in 1750, while sanitation and health services generally are doubtless a good deal better. Many (probably not all) underdeveloped areas have a more enlightened, less corrupt civil service, fairer, less rapacious courts, and more comprehensive educational systems than most of Europe had in 1750.

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In the face of all this would it not be better to stop acting as if the gap were something extraordinary, to be explained only by malevolent conspiracy, and consider the possibility that it represents merely a slight lag in the necessarily uneven course of civilization? The latter attitude is more than an abstract exercise, since it may give us some clues about how to proceed with the crucial business of closing the gap which looms so large when measured in terms of gross national product or per-capita income.

In the first place, we might give more attention to what I understand is the currently accepted view, that civilization is largely a unitary phenomenon. Until recently, historians have tended to be preoccupied with tracing the rise and fall of particular sectors of civilization, such as the Egyptian, Minoan, Greek, Roman, Arab, and Chinese. Many have inferred that a civilization could grow up almost anywhere or at any time, given the right climate.

As our knowledge of ancient times improves, however, it is becoming clear that many of the really crucial advances seem to have been made only once, and to have diffused outward to become part of world civilization. (The phenomenon of convergent evolution, though detectable from time to time, is by no means the rule.) What we have in common, both biologically and culturally, seems to be due mostly to a common origin, not to a law that history must repeat itself. Among other things, this view emphasizes that progress of any sort is hard to come by; the invention of the alphabet was a stroke of very rare if not unique genius; the development of the scientific method, the industrial system, and the mass production line, the products of a special series of situations. It is not only rather graceless but even pointless, therefore, to ask why Africa or the Americas never developed a written language and all the other technologies which have stemmed from the ability to accumulate knowledge in libraries. The wonder is that such things occurred at all.

Once we grant the hypothesis that civilization as we know it is primarily the result of the diffusion and amalgamation of techniques and concepts of more or less unique origin, our attention may center on the mechanisms of communication between branches of civilization. The technical assistance programs of the twentieth century are simply the most recent of a long series of social innovations through which men have sought to exchange ideas on how human affairs ought to be conducted. Until very recently, however, scholars seem to have given surprisingly little conscious attention to the nature of the communication processes involved.

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Most of us have a sort of wide-screen picture of Roman legions moving up into Europe and down into Africa, carrying with them the rule of law, the culture of the camp, garrison town, and city, the techniques of reading, writing, and calculating and, most tangible of all perhaps, the colonnaded Roman bath. Yet how many of us laboring on the day-to-day problems of technical assistance have any idea of how the Roman administrative system really worked, how schools were organized and financed, better methods of cultivation introduced, and the local populations encouraged to patronize the public baths?

Multivolume histories of the crusades provide detailed pictures of their origin, the ambiguous conduct of their barbaric leaders, the unseemly wrangles of the crusading armies, both among themselves and with the outraged authorities in Byzantium. We can almost count the horses stabled in the holy places of Jerusalem and the drops of blood streaming from the arms of the soldiers as they raise their hands to glorify God. At the end of this immense drama, we hear a few words about how the crusades were instrumental in bringing some of the ancient knowledge of the Mediterranean back into barbarous Europe.

The most puzzling questions of all arise when we turn to events which have taken place almost before our very eyes. Why, for example, has Japan, which deliberately avoided all contacts with the West until the middle of the last century, suddenly assimilated almost all the blessings and most of the curses of Western civilization within the short span of a single lifetime, while most of the Middle East, which contributed so much of what we think of as Western, still must be classified as "underdeveloped"?

If we leave Japan and possibly modern Turkey aside, we can make a reasonable *prima facie* case that most cultural interchanges have gone on more rapidly and effectively between the conquerors and the conquered than between independent states. On the whole, the conquered have taken more of the techniques of civilization from the conquerors than vice versa, but this is by no means always the case. The Romans were a fairly primitive people when they started on their long marches, and doubtless they brought back more of the techniques of production and the arts of good living from Greece and the Middle East than they gave in return. Even at the height of the Empire, the noblest Romans sent their sons to Athens and Alexandria to be educated.

In modern times, when the capacity for military or peaceful

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penetration depends to a large degree on the possession of just those techniques which differentiate the developed from the underdeveloped countries, the major current of lasting contributions seems to have flowed from conqueror to conquered or at least from penetrator to penetrated. But even now the importance of movement in the reciprocal direction has been by no means negligible. We know, for example, of the contribution of the China trade to the relief of the aesthetic drought which for two hundred years made life austere if not actually miserable under the Puritan theocracy in early New England. In our own time, Mahatma Gandhi's dramatic implementation of the doctrine of nonviolence provides poignant instruction to the West that the most fundamental tenet of the latter's most characteristic religion can actually be made to work. Indeed, it might be appropriate for Americans to pause here to acknowledge this bit of Indian "technical assistance" to the solution of our own most troubling social problem.

In modern times the flow of information and techniques from the developed to the underdeveloped countries has taken place largely through channels provided by the so-called colonial system. Whatever the motives of the colonial powers were—and they were in fact very mixed—in virtually all cases colonial rule resulted in improving the material productivity of the colonies and in basic cultural changes which on any common-sense basis must be regarded as improvements. Mortality rates went down, literacy rates went up, and the populations learned to value personal liberty, independence, and the legal protection of the rights of man. The curious fact is that the desire in the colonies for almost every item on the list of rising expectations was planted in them by the "colonial powers."

Why, then, is the colonial system so generally regarded as a failure, if not indeed an abomination, in the eyes of all men of good will? The answer accepted in many quarters—that the powers exploited the colonies by taking more than they gave back—is much too easy and in all probability not true in a general sense. Even in monetary terms it has never been convincingly shown that the statement is true, and the ease with which the former colonial powers have continued to increase their own national income after the loss of colonies suggests that the colonial contribution to imperial welfare was actually small. Even if the two-way flow of money and material resources between ruler and ruled was weighted in favor of the former, the disproportion was not based (except in the very early days) on stealing what was already there. The surplus, if any,

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came from the generating of new wealth, by cooperation between ruler and ruled, and redounded to the benefit of both. And let us not forget that the contribution made by the powers was drawn from the not inconsiderable fruit of five hundred years of painful social experimentation, intensive scientific thought, and energetic technical development.

It is more than a matter of abstract historical interest to enquire further into the lack of complete success of the colonial system as a venture in technical assistance. Out of such enquiry may come some guidelines for devising future mechanisms which will work better.

One point, which seems to me critical for the successful promotion of technical assistance, compels me to make some not very well informed guesses about what went wrong in the past. Even a superficial glance at the policies followed by the colonial powers reveals a very considerable variety. England seems, by and large, to have regarded her empire as a problem in administration. The establishment of law and order and the training of a local elite to carry on the tradition occupied first place. Until very recently, trade and the development of resources were left largely in private hands, and it is probably reasonable to admit that progress in this area was frequently impeded by the fear of encouraging industries which might ultimately compete with those already established back home. The Netherlands followed a generally similar course but appears to have been far more paternalistic. Unwilling to share administrative responsibility, she failed almost completely to build a civil service adequate to allow her colonies to take off confidently on their own once independence was achieved. Belgium, determined not to repeat what was regarded as the British error of developing a trained administrative elite before providing an adequate economic base, concentrated on the development of mining, industry and agriculture, and the training of lower level technicians.

The United States, though not a colonial power in the classical sense, is now thought of as sharing much of the burden of colonial responsibility. The United States did exert an important influence on China for nearly one hundred years, and it is held responsible today for many of the difficulties in South America. The situation is interesting, since, of all the so-called colonial powers, the United States refrained for the most part from taking responsibility for the maintenance of law and order or the structuring of society in either of these large areas. The "colonial" influence, though large, was indirect; it was at first conducted largely through private hands by pri-

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vate investment, missionary efforts, educational exchanges, and finally by government grants and loans, both of money and of specialized personnel. It is not my purpose to compare the relative merits of these different schemes. The fact is that, in spite of the variety of these relationships, not one has proved satisfactory to those on the receiving end.

The first and perhaps most important reason seems to be that material progress has not been fast enough to satisfy the rapid rise in expectations. Many emerging countries have been led to believe that they will advance faster on their own. The second reason is purely psychological but perhaps absolutely critical. The colonial powers never found a way to establish law and order and to instruct the colonized in the arts of modern Western civilization without implying that their own representatives were superior as people. It must be admitted that few colonial representatives ever tried very hard to exemplify the principles of equality but in any case it is extremely difficult to be convincing while saying in effect, "I know more than you do about good government, how to produce more food, advance the public health, and build automobiles, but this is only due to the curious accident that my ancestors in Western Europe happened to stumble on a couple of important new ideas a little earlier than yours did." Furthermore, the Western representatives, for perfectly understandable reasons, have insisted on maintaining living standards customary to themselves but entirely out of reach of most of the peoples they worked with abroad. Under the colonial system this built-in source of annoyance was reinforced by the fact that the apparently excessive salaries of expatriate personnel were often raised by local taxation. Under these conditions, which one could elaborate in much greater and more painful detail, the demand for independence was justifiable and its advent inevitable. In a very short time all the exchanges between the important parts of the developed and underdeveloped areas of the world will be carried on between sovereign states. This fact should help immeasurably in removing the inhibition and resentment engendered by the inequalities inherent in the old regime. Will it also ensure that the uneven, often inadequate development of the colonial era will automatically give place to sounder, more comprehensive, and above all more rapid progress? The answer is by no means clear.

In the first place we must deal with the pious assumption that a nation which offers technical assistance to another has no business attempting to alter the internal affairs of the receiving nation. Har-

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lan Cleveland has been particularly eloquent and incisive in pointing out the fallacies of this hopeful approach. There is no advanced technique for increasing production, for improving health, or for almost any other phase of modern development that can be introduced into any society unless some change is simultaneously made in traditional forms within the society. Furthermore, once the change takes hold, a whole train of cause and effect is started which brings further, even more profound changes.

Consider a country which has a very low level of literacy, few roads, a small civil service limited to stamping passports and collecting customs, and a school system consisting of a handful of primary schools and two or three substandard high schools. The few people who have managed to acquire a university education abroad have already been absorbed into the key positions of a rudimentary central government. Almost any technical improvement—malaria control, the increased use of chemical fertilizer, or the development of light industry—requires a series of wise governmental decisions involving matters far transcending the limits of the particular techniques involved. Local personnel have to be trained in the new techniques, roads must be built to transport the DDT or the fertilizer, administrative channels set up for continuing the activity after the "assistance" phase is over, and so on. In the bad old colonial days these important matters and a whole series of other activities which the economists like to call building an "infrastructure" were set up by the occupying power. Ordinarily, long experience with other colonies had given the governing power the trained staff and the judgment to carry on this complicated business with due regard for each element. Unhurried by local opinion, the governing power proceeded at a rate compatible with the flow of careful investment from outside and the ability to raise taxes within. Only a belief in miracles can make one hope that a local government of this kind could erect this complicated infrastructure without much outside help and advice, even if it had all the time in the world. But no one any longer has all the time in the world. The rising expectations have become a flood, which threatens to wash away any government not prepared to supply better schools, better health, and better food and shelter tomorrow.

The problem of the local government is further complicated because the help it knows it needs is offered from so many directions and in packages of such puzzling sizes and shapes. Representatives from many countries with different policies and special techniques

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all clamor to take a hand. How to choose, how to assign priorities for scarce labor and material among the chosen—these are indeed difficult questions.

If we now look at the situation as it appears to a thoughtful chief of a foreign aid mission of a large country like the United States, several things become clear. In the first place, he, or someone like him, together with the panel of technical experts he leads, is going to have to stay on the job for a long time. He must persuade his superiors back home that he cannot concentrate on some single program of dramatic impact, like wiping out malaria or building a huge dam, but that he must be empowered to look into a variety of other matters. To be effective, he will have from time to time to make some rather pointed remarks about the organization and recruitment of the civil service, the assignment of priorities, budgetary soundness and the like, and this is going to appear a good deal like "interfering in local internal affairs." Finally, he must prepare for the surprise and dismay of local officers. These are going to feel much as you and I would if we asked a plumber to install a new bathroom in our house and he began by asking to see our books, and then insisted that we widen the driveway so that his trucks could drive to the back door, cut down on our purchases of kitchen equipment, and train our children to brush their teeth every day so that there would be some point in *having* a second bathroom.

I am not pretending to know how to cope with these problems. All I do know is that they exist, and that any university which wants to play an important part in training and research related to technical assistance had better give a great deal of attention to determining how one country can share sovereign decisions with another without infringing on the sovereignty of either.

It may seem that I have overdrawn the picture and that there are very few countries which have as elementary an infrastructure as the one painted above. As a matter of fact, the number of already independent nations in this category is not large, but they do exist. If the bandwagon of independence continues its rapid ride over Africa, there will shortly be several more.

Let us take another and perhaps commoner case. A country with a long culture of its own, supplemented by a prolonged interchange with the West through colonial channels, achieves independence after an extended struggle. In many ways it presents the picture of a modern nation. The central government is well staffed in most of the classical departments; it has a large standing army, a

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competent police force, and excellent courts. There is a well-organized though quantitatively inadequate educational system through the university level, a public-health service, and reasonably good roads connecting the principal cities. The authorities are keenly aware, however, that many of these social services provided by government are inadequate in quality and especially in quantity. Even more severe is the lack of adequate production in both agriculture and industry. Each of these areas needs outside help of various sorts, and each no doubt has its own special problems in developing smooth cooperation between inside and outside agencies. To simplify the general problem, I shall discuss only the area about which I happen to be the least ignorant—the development of medical education, which includes the development of biological research. Those interested in engineering and the natural sciences can probably use much the same equations with but slight modifications in the value of some of the parameters.

First, let us briefly list some of the elements essential to the development of sound medical education in any country. The first requisite is good students and good teachers and a reasonable amount of space and equipment for teaching and research. A somewhat special requirement is access to a suitable hospital with adequate control over medical care and the selection of the professional staff. Once these matters are in hand, attention must be given to devising a suitable curriculum, appropriate qualifying examinations, and so on. Finally, money must be found in what seem to most educators very large amounts. All these matters sound simple and obvious enough when read off in this casual way, but the fact is that in practice the realization of each is set about with all kinds of difficulties. In quality the difficulties are much the same everywhere, but the intensity is by and large much greater in underdeveloped areas. Let us consider them one by one.

Good students are always in short supply; in even the most advanced areas we have yet to devise satisfactory methods of selecting the best. In underdeveloped countries the supply is especially short because of inadequate instruction in the secondary schools (especially in the sciences) and for general cultural reasons such as the absence of the informal technical training American boys derive from taking automobiles apart or building radio sets. Finally, the local authorities are reluctant to apply criteria of selection other than the possession of a secondary-school certificate. They have good reasons for this, such as the wish to avoid wrangles

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with outraged parents in communities in which nepotism and family pressures are traditional, and a high-minded though impractical interpretation of the principles of democracy and academic freedom. Nevertheless, the system is all too prone to fill the class with examination passers who will have to be weeded out later at considerable cost. The outside adviser, especially if he is an American, is sure to feel that the whole thing might be made more efficient if additional considerations like intelligence tests and personal interviews might be given greater weight. The local authorities (at least some of them) are likely to regard such procedures as unwarranted intrusion into "internal affairs."

The recruitment and training of faculty run into more serious difficulties. Lacking a scientific tradition, most underdeveloped countries are even poorer in trained scientific personnel than are more developed areas. Even candidates for training are in short supply, and there is less incentive to a scholarly career than one might expect. The culture is likely to accord little prestige to scientific positions, and salaries are shockingly low, especially when compared with the lush rewards of private medical practice or industry. The temptation to staff the school with part-time medical men who derive their major income from their practice is very strong. Not only is it hallowed by tradition, as well as much more economical, but the practitioners themselves often fight hard to maintain their academic connection for reasons of prestige and the control it gives them over the oncoming generation of doctors. Often the principal professors are physicians to government officials, a position which enables them to wield a disproportionate influence on the course of the school's affairs. Finally, in underdeveloped countries there is an almost religious veneration for academic degrees as perquisites for teaching or other civil-service posts. Frequently, the only degrees recognized are those which meet the standards laid down by the former colonial authority. Many first-class people who have received their advanced training elsewhere are simply left out in the cold or must use up years in cutting red tape and passing pedestrian examinations before being given an opportunity to use their nearly priceless talents and experience. Again, our outside adviser finds himself involved in trying to get salaries raised, recruitment altered, and standards of qualification broadened; and again local vested interests are likely to invoke nationalist passion in the defense of the sanctity of "internal affairs."

The problem of securing adequate control of the teaching hos-

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pital is too intricate to go into here. Suffice it to say that it is almost always very difficult for a medical school to acquire adequate control of a hospital already in being. The professional staff of the hospital is seldom qualified for teaching and research, and it resents giving place to full-time academic personnel. The board and the administration of the hospital cannot understand the sudden rise in cost entailed in raising the level of medical care to meet teaching standards. More often than not the only solution is to build a university hospital, thus causing an unexpected addition to the national budget and a distortion of the five-year plan. Even if some outside agency offers to put up most of the funds, there is the problem of inflation and the allocation of scarce labor and materials—another intrusion into local internal affairs at their most sensitive point.

The apparently innocent technical matter of providing equipment for the teaching hospital and laboratories too often runs into long arguments about foreign exchange and import licenses, even though funds for purchases are entirely supplied by outside agencies. However one may sympathize with harried treasury officials trying to hold the line against the wishes of prominent citizens to import Cadillacs, venal business men trying to bribe their way into the market for consumer goods, and other more legitimate assaults on the balance of trade, it is annoying to the representative of a foreign agency to find that the essential teaching and research equipment he wishes to give a leading medical school is held up by months or even years of negotiation with the exchange authorities. Again, and quite naturally, an attempt to get a blanket franchise for the free importation of scientific equipment is resented as an interference in domestic affairs.

We have considered some of the history and particulars of the state of affairs underlying the problems of technical assistance in the educational context. What can be done about it?

First and foremost, there should be a frank admission on both sides that technical assistance is not something that can be injected into the body politic to exert its effects all by itself. If it is going to do any good, it must interact with and modify a whole range of ongoing activities inside that body. There should be no hesitation on either side to discuss such possibilities as can be foreseen and to make them part of an explicit agreement at the highest level of government. To be specific, an American university or scientific institute which undertakes to provide technical assistance to a sister institu-

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tion should satisfy itself in advance that salary scales, selection procedures, curriculum standards, examination techniques, and import arrangements for scientific apparatus will all be modified in ways that are agreed on. Since obviously not all the essentials can be agreed on or even identified in advance, it is necessary to set up some sort of permanent negotiating procedure which will ensure that matters calling for decision will be brought expeditiously to the level at which the decision can be made.

Here it must be remarked that many formerly colonial areas are still operating under administrative mechanisms designed to maintain the status quo. Even the smallest decisions are endlessly referred upwards, until finally even simple matters like the granting of fellowships for foreign training reach cabinet level. Established by the colonial powers for obvious reasons, such procedures often fit all too well into an ancient cultural tradition of absolutism and prove surprisingly resistant to alteration, even by modern democratic governments.

The outsider cannot help feeling that much greater delegation of authority and decentralization would make for much greater efficiency all around. More specifically, those of us with a particular interest in technical assistance as it concerns educational and research institutes would wish strongly to recommend that such organizations be given the kind of autonomy enjoyed by the better American state universities, with independent boards of trustees or regents, direct access to the legislature, budgets granted en bloc, and so on. It would be especially convenient for the development of science if the authorities could be persuaded to set up independent research councils like the British Medical Research Council or the National Science Foundation. At the present time such organizations are more or less rare in the underdeveloped countries, and when they do exist they usually operate under close surveillance as parts of government ministries.

The existence of independent universities and research councils that are free to negotiate directly with the outside organizations offering aid and to adapt policies for recruitment and staffing, modifications of curricula, and building plans within the over-all budgetary limits provided by government would greatly facilitate the process of technical assistance in so far as it is concerned with research and higher education.

Some mention should be made of a much more difficult matter.

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Unfortunately, there is a fairly large class of underdeveloped countries in which the social structure is still quite similar to the one prevailing in eighteenth-century Europe—a large, rather ignorant lower class made up of agricultural workers and an increasingly important city proletariat, a small but growing middle class, and a very small but very rich upper class which controls most of the land and a considerable fraction of the commercial life. These three classes differ from one another in their rising expectations, and it is something of a problem for agencies of foreign aid, be they public or private, to deal equitably with them all. In actual practice, what happens is that foreign aid frequently becomes identified with the interests of the topmost class. In many instances, internal hostilities which might have been directed at this class are diverted to the country providing technical and financial assistance.

There is a real problem here, one which will take more than fine phrases about good neighborliness to solve. As long as a traditional governing class is in control of affairs, it is inevitable that negotiations for technical assistance must be carried on through its representatives. Not only are they the only people who can make the decisions, they are likely to be the only ones who have sufficient training in foreign languages, scientific techniques, and managerial "know-how" to make the local program effective. Social contacts between the foreign technicians and the local population are again quite naturally concentrated among the higher classes. Nevertheless, it cannot be denied that the upper classes in general are unlikely to be enthusiastic about some of the implications of the social and economic changes which always accompany the modernization of any society.

Let me give a very simple example. The technical improvement of agriculture, undertaken to better the income of the small proprietor and the nutrition of the whole population, is more than likely to result in a lowering of food prices with a concomitant decrease in the incomes of the landowning class. Popular pressure for land reform usually increases at the same time and further threatens the income and status of the old regime. The high taxes necessary for improved public health services, universal education, good roads, and all the other things that make modern society modern are not likely to make the only class with money enough to pay for them shout for joy.

As a corollary to the first basic requirement of recognizing the implications of technical assistance, we must face the fact that, once

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a society embarks on a program of technical improvement, it is committing itself to a large degree to what *Time-Life* editors call the permanent revolution. Too often in the past, neither the country offering nor the one receiving technical assistance has been willing to acknowledge this obvious point. The result is that those who do recognize the need for change come to regard the program for technical assistance as just another method of shoring up the crumbling foundations of an obsolete social structure. In their dismay they turn far to the left in search of revolution by other means. Somehow the advanced countries, especially the United States, must find a way both to admit to themselves and to convince the underdeveloped countries that what they do in fact have to offer is a revolution—a revolution that in the long run will produce more good at far less cost than any other revolution on the market.

I make no apology for going so far into these economic, social, and even political matters. It might not be a bad idea when considering requests for help in improving technical education abroad to include in the agreement the understanding that the cooperating institution will give an important place to instruction in the history of the social and political ideas which made the technological revolution possible in Western Europe and the United States. I cannot help wondering whether the current misunderstandings between North and South America may not in part stem from the fact that there is no chair of North American history in South America, and precious little attention in the United States to South American history.

In view of all the basic difficulties inherent in transferring the fruits of one culture to another, it is high time that we gave up talking as if the problem were already understood. Our great universities are perhaps in the best position to approach the situation with the investigative attitude that is needed. Too often, however, they leave their tradition of research at home and turn to their overseas obligations in a purely didactic frame of mind. They appear to feel that scientific knowledge and technical know-how can be put up in neat packages and sent abroad for use by the consumer more or less as is. Thus we find in Africa university colleges which are carbon copies of Oxford and Cambridge, even down to the last stitch in the gowns of the honors student who recites a Latin grace before dinner in hall. On a continent in which perhaps nine-tenths of the current deaths are preventable, there is no first-class department of preventive medicine, largely because the European schools on which

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these universities are modeled pay little attention to this subject. Heavy farm machinery designed to save high-cost labor is imported at great expense in many areas in which the primary problem is to find productive jobs for an excess of farm workers. The list of examples of such inappropriate behavior is unhappily almost endless. Yet this is after all only the natural result of the general belief that the advanced countries are so far ahead of the underdeveloped ones that almost anyone or anything which is only second-rate at home will be first-rate overseas. Too often it turns out that a second-rater at home may easily become a third-rater overseas, since he lacks both the analytic ability to detect the essential differences in the environment in which he must apply his well-mastered techniques and the creativeness to adapt the latter to local conditions.

A great university is especially well fitted to approach the problem of technical assistance without preconceived ideas and with real scientific curiosity, for after all this is the way scholars are supposed to approach all problems. In pursuit of this objective it should be prepared to assign its best people, those with the most penetrating curiosity and the most flourishing inventiveness.

In the early days of the colonial period, conditions in Europe, especially in Scotland, were such as to impel many bright and energetic young men to engage their intelligence on unsolved overseas problems. For example, the pandemic disease malaria, which had plagued Europe itself as well as more tropical areas since the beginning of history, found its solution largely at the hands of men who dedicated most of their lives to underdeveloped countries. Charles Laveran, who first described the parasite, was a French military surgeon in Algeria; Sir Patrick Manson elaborated the theory of insect transmission from his work on filariasis in Amoy; and Sir Ronald Ross, who demonstrated that mosquitoes could transmit the malaria parasite, was a member of the Indian Medical Service. Once these eminent men had worked out the basic theory in underdeveloped areas, the subsequent "applied" studies were carried out, ironically enough, in relatively well-developed Italy. This story seems particularly appropriate, since it shows so neatly that technical assistance is not just a matter of applying what is already known or even of building a new technique on existing basic knowledge, but may actually require the discovery of an entirely new basic principle. And for this the best possible men are needed.

Even though we would not resurrect the laws of primogeniture or restore the rural and urban poverty which drove so many good

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men to seek their fortunes overseas in the nineteenth century, we can and should do more to elicit our best talent to meet the continuing challenge. Our technical schools might try to give the same sort of recognition to faculty members who display the peculiar combination of social and technical inventiveness necessary for success in an unfamiliar environment as they now do to those who discover a new particle while working comfortably at home with the new accelerator.

Anyone having any contact at all with the underdeveloped countries must by this time have become aware of the very large demand for the technical training of subprofessional personnel, skilled artisans, straw bosses, and the like. The demand as usually formulated takes the form of requests for aid in setting up technical or vocational schools. It is extremely difficult for me to believe that this is the best way of going about training the necessary people. It is true that many advanced countries do have vocational schools, but they seem to have developed rather late and, at least in part, in order to fulfill the legal requirement for universal secondary education. The classical method of turning out skilled workers and artisans is some form of the apprentice system or training while on the job, and one wonders why the educational planners in the emerging countries seem to pay so little attention to adapting the best features of this system to local conditions. I wish that some capable group with no ax to grind would submit the situation to careful study.

Most of the emerging countries are extremely hard put to it to provide adequate primary and secondary schools for the bulk of the population, and advanced training for the badly needed professional elite. Nigeria, for example, is already spending 41 percent of the national budget on this problem without coming anywhere near to meeting the needs of the secondary schools and universities which are already in the planning stage. It would seem most undesirable to divert capital funds and teachers from these essential items in order to establish vocational schools, unless the latter were absolutely necessary. There seems good reason to believe that in a good many fields they are not.

Most of the large construction work undertaken in underdeveloped countries necessarily relies on what initially is completely unskilled labor. It is amazing how quickly such workers are trained on the job to perform as bricklayers, electricians, plumbers, or carpenters. I remember walking through the very large, very modern, new teaching hospital in Ibadan, Nigeria, after the shell had been com-

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pleted but before the finish had been applied. This allowed a fairly close appraisal of the workmanship produced by artisans of several different kinds. On the whole, it was excellent—much better, for example, than that observed in a similar tour through one of the unfinished national institutes in a well-known and technically advanced country of Eastern Europe. With some pride, my guide explained that almost all the handwork on the building was done by local labor, trained and supervised by some forty experienced bosses brought along by the British contractor.

I could not help wondering whether this pattern, which has been repeated over and over as a matter of necessity, might not serve as the basis for a consciously designed plan for the training of technical personnel. There is an immense amount of construction of all sorts to be done in the underdeveloped countries. Much of it will in one way or another be supervised by foreign engineers and other technical personnel. If these were taught to regard the teaching of the classical crafts and the more modern mechanical techniques as an important part of their jobs and were given some instruction as to how to go about it, would not this go a long way toward solving a problem which now seems to loom so large in the minds of responsible local governments? It would certainly pay the latter to look into the possibility of writing construction contracts so as to include the training of a specified number of certified skilled artisans to work on the primary job of dam building or factory construction. The extra cost would be trifling compared with that of building and staffing separate *ad hoc* vocational schools or institutes.

Could not institutes like the Massachusetts Institute of Technology, which will increasingly be training personnel for the task of overseas development, give attention to the problem of training subprofessional personnel? It is not proposed that they shoulder this responsibility directly, but there are two ways in which they could help indirectly: first by taking the problem seriously enough to study the various alternatives, perhaps in the form of pilot projects, and second, as mentioned above, by including in the educational programs of engineers planning overseas careers some guidance in developing the latent talents of the labor force with which they will have to deal.

At the other end of the spectrum of technical education, a few words should perhaps be said about a quite different problem. The increasing tendency to segregate certain sorts of research in separate *ad hoc* institutes rather than include them as parts of a general uni-

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versity program in research and education. This tendency has already progressed rather far in some countries and promises to continue to what may become a dangerous extent unless the responsible authorities become clearer about the relative advantages and disadvantages of this procedure. The arguments ordinarily put forward for separating advanced research in special subjects from the activities ordinarily conducted in universities may be briefly summarized as follows:

1. The need for new knowledge is so pressing that every effort should be made to make its pursuit as efficient as possible.

2. Research talent is so rare that it should be carefully protected from dissipating itself in other more or less irrelevant activities, such as teaching and participation in university administration.

3. A group of highly trained people working together on a single project will be more productive than the same number of persons scattered through a number of institutions.

4. Existing universities are so bogged down in a past tradition hostile to research in the natural sciences, so encumbered by outworn methods of recruiting and compensating personnel, so preoccupied with the teaching function, and so encumbered with red tape that they are sure to smother any attempt to establish advanced research within them.

Arguments as persuasive as these cannot be dismissed lightly and in fact have led in almost every country in the world to the establishment of special-purpose research institutes. Perhaps the most famous are the Kaiser Wilhelm Institutes, which have contributed a great deal to the advancement of science, especially in the first quarter of this century. The Pasteur Institute in France, The Rockefeller Institute in the United States, the National Medical Laboratory at Mill Hill in the United Kingdom—all testify to the success such research institutes may have under certain specified conditions.

As the newly developing countries seek to establish scientific work of international standard, it is important that they not be misled by the isolated and limited success of such institutions in the advanced countries. In the first place, it seems necessary to recognize that, though the quality of the work of these institutes was, and still is, high in certain instances, at no time has it represented anything like a major fraction of the research done in the country as a whole. Germany is undoubtedly the country in which these institutes once reached their highest development. Although the situation is

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a complicated one, it is perhaps not irrelevant to point out that during the same period the German universities declined to such a degree that they proved unable to produce a continuing supply of qualified research workers for the future. Because of the very serious damage to the universities from other causes, it is impossible to draw a firm conclusion, but it is nevertheless important to observe that the independent institutes, now known by the name of Max Planck rather than Kaiser Wilhelm, have been forced to draw ever more closely into the university atmosphere and that the directors of some of the best of them now hold joint appointments in the institutes and in the universities proper.

It is now appropriate to take a closer look at some of the reasons for believing that it is almost fatally dangerous to separate any large fraction of the nation's research effort into separate *ad hoc* institutions.

1. Although the gathering together of the nation's best talent in a particular field may result for a brief period in a high productivity along a particular line, this productivity is almost certain to decline in the long run. One reason is that no single subject, such as nutrition, infectious disease, atomic physics, or organic chemistry, can develop very far without constantly being nourished by essential, new ideas developed in other disciplines. The university with its company of scholars representing all fields of knowledge is in a much better position to encourage the flow of new ideas from one field to another than is the specialized institute.

2. The separation of advanced research from all but the most advanced levels of education does a subtle but serious damage to the research process itself, and irreparable harm to education. However the research worker may resent the necessity of taking off an hour or two a day to perform teaching duties, in the long run most experienced people will admit that the constant contact with young minds enforced by the teaching obligation plays an essential role in keeping the research worker familiar with progress in the broad fields related to his own narrow specialty. Furthermore, it requires him constantly to reappraise the assumptions on which his own work is based, since it is well known that newcomers to learning encounter the greatest difficulty in understanding the often nebulous assumptions or axioms on which a given field of knowledge is based. The divorce between the best research talent and the oncoming generation of students makes it exceedingly difficult to recruit new talent into the field. In general, the student who might be-

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come an enthusiastic worker in subject X becomes discouraged by the low level of teaching provided by the mediocre personnel left in the universities, and so he drifts off into scholarly work in another field or more frequently into business or a profession. Even in those rare cases in which an especially brilliant student survives inadequate teaching, he is relatively unknown to the administrators of the research institute, who must grope blindly in trying to fill their junior staff positions.

3. Closely related to the above but so important as to deserve a separate heading is the damage done to the educational process in the university by draining off all the competent and brilliant people to man the institutes. How can an institution prepare its students for an active intellectual life, if a great majority of its faculty is made up of people who are not active enough intellectually to deserve a place on the staffs of the research institutes? It is very difficult to impart knowledge, especially knowledge of the discovery process itself, unless one is actively engaged in discovery. When it is divorced from the research atmosphere, the transmission of knowledge degenerates into the mere transmissions of lists of items to be memorized, or, as is more often the case, to be forgotten as soon as the examination period is over. The whole sense of wonder and excitement about new knowledge which should characterize university teaching disappears, and the nation is left without a new generation to carry on the work which may have been started so brilliantly during the early days of the research institutes.

4. Finally, in those countries in which the establishment of research institutes is largely undertaken because of the feeling that the current universities are inadequate to the job of encouraging research on a broad front, the institutes too often serve merely as an escape valve for the pressure which would otherwise push toward the necessary reform of the university structure. It would be invidious to cite specific instances, but anyone familiar with research and education on an international basis can think of numerous illustrations. The only way to reform a moribund university system is to reform it. It does no good in the long run to seek to avoid the symptoms by establishing new institutions to perform one or another of the university's historic functions.

As this essay has tried to show, both communication and discovery are essential to the development of new nations, and both flourish best in the environment of the university.

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GORDON S. BROWN

New Horizons in Engineering Education

About two years ago Elting Elmore Morison was a member of a small group working with C. Richard Soderberg on a study of engineering education. It culminated in the report, *A Proposal for Experimental Developments in Engineering Education*.[1] In the course of the study Professor Morison coined the definition, "Doing engineering is practicing the art of the organized forcing of technological change." This definition seems particularly pertinent to the problems discussed in this issue. In a society in which science and engineering are both pursued vigorously, it connotes a turbulent, changing scene. In the words, "practicing the art," it recognizes the need of coupling technological with human factors, such as talents and tastes and the wide variability of human values. The word "forcing" is indicative of the fact that leadership in engineering involves the capacity for breaking through into new domains, rather than merely extending present ones.

To appraise Professor Morison's definition fully, we must consider the actions of engineers, working either as individuals or as teams, throughout the whole spectrum of technological endeavor. At one end of the spectrum are people whose work is of a highly theoretical character; it is classified as engineering because of its orientation rather than because of its tangible substance. At the other end are the builders of machines, structures, production facilities—engineering achievements that everyone can see. Within these extremes are people whose activities are in research, development, design, consulting, even the education of engineers. Here we encounter a highly variable mixture of abstract effort with physically tangible effort. To a degree, this mixture explains why the public image of the engineer varies so widely.

Professor Morison pointed out that, whereas for students in

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many intellectual fields the acts of learning, discovering, and explaining are sufficient ends in themselves, for most engineers they are not. Because the works of engineers taken as a whole result in making things that people use, the engineer must supplement his learning with purposeful action. An exacting requirement of engineering is that whatever is built must work, and ultimately it must be within the economic reach of the user. When engineers set out to build things, they hope to make something new and superior to what has been built before. As they proceed, they find their materials and the constraints under which they must work constantly changing, because (1) technology itself is continually increasing in sophistication as science advances, (2) the "forcing of technological change" continually increases the intellectual effort demanded of engineers, and (3) the complexity of the decision-making element in major engineering continually increases as the maze of factors from which an optimum design must emerge continues to grow.

As we look back to the undergraduate education in the United States during the decade or so preceding World War II, we see that engineering education was then based on the assumption that what students learned in college would serve them throughout most of their professional lives. The technical principles underlying much of the engineering work of that era were clearly circumscribed. Much of it still rested on experience acquired in designing and building works that came into being before the scientist had explained precisely why such machines and devices worked. Many engineering professors then had a relatively firm conviction as to what their students should be taught in the way of art and practical "know-how" in order to achieve enduring professional careers. Because the steam engine was a dominant element in power machinery for about a hundred and fifty years after the work of James Watt or because the vacuum tube was the dominant factor in electrical communications for about forty-five years after De Forest's initial work, it was possible and perhaps proper to think of preparing young men for their careers by teaching them how to build things and by indoctrinating them in current art and practice.

This doctrine stemmed from the philosophy that technology would not change appreciably during an engineer's lifetime. It assumed, falsely, that engineers would merely build machines to a conventional pattern and keep them running. It overlooked this fact: whereas up to about the turn of the century science and basic theory were extensively concerned with explaining many things that en-

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gineers had done by the application of art and intuition, the era was dawning when the discoveries of scientists would evolve new theories that would predict numerous advances in engineering yet to be made. It was not recognized that the new findings in science were steadily unsettling the shape of technology and that the tempo of this unsettling would increase. It took only about ten years for engineers to mass-produce jet engines after the basic concepts of jet propulsion were understood. Almost overnight the skill of many engineers in designing piston engines became worthless. Now rocket propulsion and nuclear propulsion threaten to compete with the jet engine. In a different field it took only about five years to achieve the mass utilization of transistors, after William Shockley and John Bardeen perceived what solid-state physics predicted for semiconductors. Many electrical engineers whose education was based narrowly on vacuum tubes found it difficult to adjust to the technology of the semiconductor era. Now, as one speculates on the aspects of cryogenics, there appears the likelihood of revolutionary developments involving superconductivity in the microminiaturization of complex systems, on the one hand, and in the development of massive power-generation systems, on the other, pre-empting many domains of technology that only a year or two ago were thought to be secure.

Furthermore, the old doctrine overlooked the fact that, in addition to being the instigator of change in his own profession, the engineer would become the efficient agent of rapid change in the economic, social, and cultural environment of the world in which he would live. The development of the automobile and the giant facilities for its mass production have interacted with older modes of transport of both goods and people. The result is not only an emerging crisis in transportation but also along with it a need to assess the role of the city in relation to urban development before our large cities decay and much natural beauty is destroyed by ill-planned urban development. Developments in automation have changed the value of man's labor. Developments in aeronautics have changed man's scale of time and distance. Developments in space technology and weapons have changed both the roles and the responsibilities of nations and their leaders.

Thus it is not surprising that the task of educating young men for an engineering career is now taxing our institutions of learning in a host of complex ways. The diversity of needs, desires, and opportunities, both educational and professional, is so great that no

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single pattern of what an engineering education ought to be will serve. Many of the issues involved are being debated in government, industry, and the professional societies, as well as in colleges and universities. Education is subject to many constraints and much controversy even when the situation is fairly stable. In this time of rapid engineering advance, the constraints and the controversy take new forms as the role of the engineer in society continues to expand and as the character of engineering continues to change. In today's world a large corps of educated engineers is clearly a powerful instrument for enhancing human activity in every nation.

Who Is an Engineer?

Let us first identify some of the distinguishing characteristics of engineering so that we can answer the questions: Who is an engineer? What training should he get? The answers are not easy to state. In attempting them we often become trapped in semantics or think narrowly in terms of past practices. Many of our engineering schools are organized into disciplines, such as mechanical, electrical, civil, and aeronautical engineering, as though there existed clear-cut types of effort on which we could put a label. We know, however, that these labels no longer represent an accurate image of the kind of career a graduate engineer may have. Abundant evidence shows that within about five years after graduation most successful graduates achieve broad responsibility in work that is often quite different from what one would expect from the labels of their degrees.

These issues were discussed at the Conference of Commonwealth Engineering Societies in 1954 and the Conference of Engineering Societies of Western Europe and the United States in 1955. The terms "professional engineer" and "technician" were defined as follows:[2]

> A professional engineer is competent by virtue of his fundamental education and training to apply the scientific method and outlook to the analysis and solution of engineering problems. He is able to assume personal responsibility for the development and application of engineering science and knowledge, notably in research, designing, construction, manufacturing, superintending, managing, and in the education of the engineer. His work is predominantly intellectual and varied, and not of a routine mental or physical character. It requires the exercise of original thought and judgment and the ability to supervise the technical and administrative work of others.
>
> An engineering technician is one who can apply in a responsible manner proven techniques which are commonly understood by those who

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are expert in a branch of engineering or those techniques specially prescribed by professional engineers.

The report goes on to describe some of the duties typical of the work of engineering technicians, such as:

> . . . work on the design and development of engineering plant and structure; erecting and commissioning of engineering equipment and structures; engineering drawing; estimating, inspecting and testing engineering construction and equipment; use of surveying instruments; operating, maintaining and repairing engineering machinery, plant and engineering services and locating defects therein.

In the above statements there is an emphasis on many desirable qualities; but I sense an absence of stress on scientific competence or on qualifications that would stimulate engineering breakthroughs in fields that are emerging because of new scientific discoveries. The engineers thus defined would not appear to stand out because of their achievements at "forcing technological change." The words "analysis and solution of engineering problems" connote the follower rather than the leader. There is a great need these days for the engineer whose main efforts are in opening up new vistas, who is very much at home in physics, mathematics, and chemistry, who has close relations with scientists, who is strong in scientific concepts and the ability to synthesize them, and who is motivated to exploit them. Sometimes this person is called the engineer-scientist.

We detect a paradox here, for, when a creative engineer designs for the future, he must often work as a scientist. Also, to achieve some of the great advances in science, many scientists have worked as engineers. Designing for the future calls for a keen insight into man's needs, a profound appreciation of modern science, a vision of the future, and a desire to achieve it. Such an engineer has the intuitive capacity to recognize that never in history has man invented a really significant device, machine, or system which, after being used a relatively short time, has not been called on to perform far in excess of the capacity its designers intended. This kind of engineer recognizes that change is inevitable. He instinctively realizes that the improved practical applications of the atomic and space age have burst into being because engineers have united the long accumulated background of fundamental science, mathematical theory, controlled basic experimentation, and contemporary industrial practice. It matters not whether he is prodded by his internal motivation or by external spurs. He performs the creative role that is one distinguishing characteristic of a much needed type of engi-

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neer. Thus, the above definitions of professional engineer and engineering technician are not, in my view, adequate.

The Work Function of Engineers

By gross oversimplification one may identify three broad categories of engineering work function,[3] knowing perfectly well that the specific kinds of competence in any individual are a blend of his natural gifts, what he learns in college, and what he learns on the job and in living and observing. First, there are those engineers who have the talent for detecting deficiencies in the capabilities of existing engineering devices or systems, and whose impulse is to conceive from abstractions or from a broad body of science wholly new, superior devices or systems. Such engineers can relate quite abstract and seemingly unrelated concepts in novel, purposeful ways that lead to something new and useful. They are composers, rather than arrangers. Their work is predominantly intellectual, and it depends on a profound knowledge of science. They may work as scientists, but their knack of seeing the useful rather than searching for the unknown characterizes them as engineers.

For example, the engineers who perceived the need for increased capability in computation and who conceived and pointed out applications for giant digital machines long before the first one was built belong in this category. So do those who can assess the dwindling fossil-fuel supply and chart the way to nuclear power or to the direct conversion of cheap heat into usable electricity, using concepts of solid-state or plasma physics. For engineers in this category a four-year program terminating with the bachelor's degree is insufficient. Only by pursuing their studies to the doctorate can they master the breadth of knowledge they must command in order to develop their latent talents to the required level.

In another group are those engineers who can devise and build systems of engineering works by an orderly, creative, ingenious arrangement of the knowledge of the day. These are the creative arranger or inventor, rather than the composer. Their work is also highly intellectual and creative, but their major purpose is to devise or design, to build, and to make things work. They are highly sensitive to engineering feasibility and to economics. These perhaps represent the "professional engineer" cited above. This type of engineer works closely with his colleagues in the first group. He is the person who, in the main, reduces the more theoretical work of his col-

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leagues to a practical form. He appears in great numbers in development laboratories, in design establishments, in production or manufacturing planning. He must be very much at home with the engineer-scientist. He too must be educated beyond the bachelor's degree and through the doctorate, but he must specialize in design and engineering development, in which he should acquire a highly negotiable competence.

Finally, there is the group of persons expert in assembling, operating, and maintaining complicated machines and engineering works, from drawings, descriptions, or experience. In one sense they are the custodians of technology. They are not second-rate citizens. In both today's and tomorrow's era of technology they are needed in very great numbers. They must have a high degree of competence in mathematics, physics, and related sciences, but not to the depth demanded of the persons in the first two categories. For many of them a bachelor's degree of a terminal character from an engineering college provides an ideal training.

As a consequence of the bigger and more complex industrial machine, however, the manpower to keep it running is becoming more critical. The number of custodians we require becomes greater; their skills must be upgraded. To hold a custodian's responsibility for a modern jet passenger aircraft calls for a high degree of skill and considerable understanding of how its components work. But the person who serves in this role in our industrial complex can well be one who could neither have designed the aircraft nor conceived it in the first place.

In the United States the formal engineering education of people for this last category is predominantly the responsibility of technical institutes. These generally provide two-year curricula beyond the high school. They are an essential element in our society. Like the universities and degree-granting technical colleges, they face perplexing problems as the fields of engineering multiply and the levels of custodian skill increase. As one appraises the effectiveness of our total system for educating a technological work force, one sees evidence that little attention is being given to the development of our technical institutes.

The Creative Element

Intellectual creativity and inventiveness are dominant characteristics of the engineer who practices the art of the organized forcing

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of technological change. This point is often lost when engineering is defined merely as applying science to the benefit of man. The creative aspect rests in an engineer's ability to relate seemingly unrelated events of nature, whether abstract or tangible, in quantitative ways, to make new and useful theories, materials, devices, complex systems, and especially systems in which men interact with machines.

Within this context, the engineering leaders who a hundred years ago gave us our great systems of electric power were a very creative lot. They had the intellectual ability, the creativity, and the definiteness of purpose to understand and to relate such phenomena as burning coal for heat to generate steam, the use of steam to rotate a shaft, the rotation of a shaft within a configuration of metal and electromagnetic fields to generate electricity, and the use of electricity to make light. Since their day, man's knowledge of his material resources has changed, his knowledge of science has increased, his expectations have magnified. We need engineers who can coordinate various kinds of knowledge, which offhand seem unrelated, into purposeful forms for uses as yet unknown. The creativity here implied must couple new factual knowledge acquired by study in depth with powerful viable procedures for implementation.

To develop students with creative competence, we want curricula which will teach the basic findings that scientists have given mankind by their organized and objective documentation of the laws of nature, so that engineers may know as precisely as possible what happens and how it takes place.[4] We then want curricula to teach both science and the scientific method, to provide quantitative models called mathematical theories, by which engineers bring together in logical sequence the multitude of observed and seemingly unrelated events of nature. This quantitative organization of physical phenomena, often called model making, is the key to much of what is called engineering analysis and synthesis. We also want to teach engineers how to predict the performance or capability of the products of designs not yet made. We want to enhance the ability of our future engineers to create and devise new applications. We can do these things only if our universities and technical colleges provide the appropriate environment.

New Programs and Procedures

It will be helpful to identify some of the guideposts for charting

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the programs and procedures that engineering educators should follow as they adjust to these changing times. On the one hand, the pace of scientific discovery has become almost explosive. A multitude of new possibilities for the engineering of needed machines, devices, and systems have been proposed. On the other hand, the emerging new fields—such as nuclear power, sophisticated computers, new materials, and orbiting satellites—have interacted with the traditional fields, with one another, with new scientific discoveries, and with the day-to-day activities of man, in ways that are causing some areas of engineering to decay while others burst forth into new growth.

Tomorrow's engineer is expected to know much more science than his predecessor of only a decade ago. Whereas he once could work alone on fairly straightforward tasks, today he must collaborate with people in many different disciplines and seek the optimum from among a continually expanding number of often conflicting conditions. Throughout his professional life, he will have to acquire knowledge in areas quite different from those in which he was trained in college. He must be prepared to extend the base and increase the level of our standard of living. He must be trained so that in the world of his generation he will have the capacity to enhance the numerous aspects of the science with which he will work, to be a scientist when necessary, to be able to design for the unknown. He must be able to weave intelligently, with imagination and judgment, the discoveries of both scientists and engineers into the total fabric of society, as he works at solving the complex problem of his own era. He must have an interdisciplinary capacity, to cope with changes far greater than those confronting his predecessors. He must be prepared for an increased involvement in the economic, social, and political arena. He must have the fortitude to deal with changes that are not only revolutionary but even catastrophic.

For the last five years in the United States, the view has been widely held among professional engineers and engineering educators that too few high-school students express an interest in a career in engineering. They cite figures to show that a great majority of secondary-school students with aptitude for the physical sciences express a preference for studying physics or mathematics in college. Much effort has been expended in telling high-school seniors and college freshmen about the differences between engineering and science, and too little in telling them about their similarities.

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The importance and challenge of a careeer in engineering as opposed to science has become confused in the public mind as a result of the lack of distinction between the words "science" and "engineering" on the part of the public press. In fact, such a distinction is not always easy. In view of this, it would appear more profitable for engineering educators to accept the lack of any clear distinction and to recognize that during his early training the engineering student has no alternative but to gain essentially the same mastery of the basic sciences as is required of a scientist. Because of the inherent intangibility in coupling purpose, action, and judgment with theoretical competence, and because modern sophisticated theoretical techniques appeal strongly to our brightest students, we should not be very alarmed if, at the undergraduate level, their intellectual temper and attitude are strongly influenced toward essentially analytical studies. Even if many do conclude that it is preferable to concentrate on science, it would seem proper to tell them, with a note of humor, that "the engineer is the scientist who has completed his education," and then in the upper-class and graduate years to offer programs in engineering which will capitalize on the challenge in this remark.

On the other hand, many students enter college with the firm conviction that they do wish to become engineers. Though the end result of the education acquired by an engineer whose early technical training is primarily of a scientific nature may differ but little from that acquired by one who from his freshman days wishes to concentrate on engineering, we should recognize the importance of providing the student initially oriented toward engineering with a challenge that will foster his enthusiasm.

I do not mean that we should not do our very best to explain to entering freshmen the roles played by scientists and engineers. Only thus can we help the undecided students to choose the type of training most personally rewarding. But it is not easy to present this explanation. Whereas the high-school senior or college freshman is given opportunities for meeting teachers who are scientists and for experiencing the thrill of mathematics or physics, he has little significant involvement with exciting examples of engineering. Neither in high school nor in his college freshman program does he have extended contact with teachers who are engineers or whose teaching can open his eyes to the challenge of engineering. How, then, can he be expected to choose engineering as a career? One way to help him, perhaps, is to have professors in engineering collaborate with

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professors in science in teaching the freshman and sophomore subjects.

It appears right and proper therefore to encourage young people to study seriously the fields of physics, chemistry, and mathematics. In fact, we should be careful not to discourage any who appear headed for graduate school from pursuing their ambition for a first degree in one of the physical sciences. Certainly, achievement in engineering is more secure when an engineer has a first-rate mastery of the fundamentals of basic science.

Revising Curricula for Engineers

A major reappraisal is called for in the total program of education for leadership in a technical career, from secondary school to the doctor's degree—a reappraisal that should take place simultaneously in our educational institutions, in industry, and in government. Happily, a nation-wide major reshaping of the programs in mathematics and physics in the secondary schools is under way. At the college level, ways must be found to disengage the current mores and doctrines of curricula from the great heritage of the past. It has bequeathed us a compartmentalization of disciplines that presents great obstacles to the efficient transfer of new ideals from scientist to engineer to industry.

Engineering teaching, curricula, and facilities in many disciplines are outmoded and inadequate. They are often the captives of a great past in ways that retard the advances that would provide the adaptability to change that society expects of its engineering leaders, if industrial advances are to keep abreast of a continually expanding economy. We have before us, therefore, a multiple task: first, to equip engineers with the most up-to-date and profound understanding of the total body of science; second, to equip them for learning anew as society moves forward; and third, to convey to them some of the art of making the complicated decisions involved in bending the forces of science to the design and building of the multitude of needed new applications and sophisticated machines, whose very nature is unknown while they are being educated. Finally, we must develop their capacity to make their contributions work as civilizing influences in society. Too few schools even approach achieving these objectives.

As remarked above, the total environment of a technical university must be understood, if its effectiveness is to be enhanced. In its

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simplest terms, a university comprises a society—students, faculty, and administration—whose main focus should be on learning. Too often the emphasis is on teaching, to the subordination of the essential role, namely, that the university should be a powerful agent for generating new ideas, new philosophies, and new doctrines that meet the needs of the future as well as the present.

As Sir Eric Ashby has ably said,[5]

> If universities were to become community service stations responding to this and that popular demand, their integrity would be endangered and their influence weakened. . . . They must be ambivalent. . . . It is essential that they transmit the known knowledge but essential also to break through into new knowledge even if from time to time it threatens the stability of their society. . . . Their patron today is the taxpayer. . . . They run the risk of being the victims of the despotism of the majority. . . . They must add even dangerous knowledge.

Fulfilling their important purposes becomes difficult for many engineering units in universities, for,[6]

> . . . teaching and research in technology are unashamedly tendentious and their tendentiousness has not been mellowed (as it has for medicine and law) by centuries of tradition. Technology is of the earth, earthy: it is under an obligation to deliver the goods. And so the crude engineer, the mere technologists (the very adjectives are symptoms of the attitude) are tolerated in universities because the state and industry are willing to finance them.

As one appraises the trends in higher education in the Western world, evidence of a new attitude toward engineering and toward a liberal education appears. The tendency to associate a liberal education only with subjects in the arts is giving way on many campuses to the notion that liberality is "a spirit of pursuit" rather than a grouping of subjects. That a nation's culture, its patterns of thought, and the scope of its intellectual vision are now extensively influenced by science and engineering is an idea that is gaining wide acceptance. Majors in the arts are now called on to gain more than a rudimentary knowledge of science and technology, just as engineering and science majors have been called on for at least three decades to allocate about twenty percent of their studies to the humanities. The prospects are brightening for a gradual coordination of these two cultures, but not, I believe, without a change in attitude on the part of those who are taught, those who teach, and those who administer.

On most campuses the compartmentalization of disciplines is

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deeply entrenched. Arts professors in general talk only with arts professors and teach only the arts. Mechanical engineering professors talk principally with mechanical engineers and teach only mechanical engineering. As stated, this is somewhat exaggerated, but the situation does not resemble even vaguely the interdisciplinary character of the work of mature engineering leaders.

Can our present educational structure meet the test of the times? If we assert that we want our students to become men of breadth and vision, able to integrate knowledge, we should ask ourselves whether we are giving them the opportunity to see knowledge in its totality. I believe we are not. I believe that in too many instances curricula are fragmented and the responsibility for integration is left to the student. I believe further that, if we examine the factors for strength in a university, we shall detect some important changes. As I appraise my own institution, I conclude that its strength lies in the self-generative forces for the unfolding of new knowledge that are provided by on-campus interdisciplinary research, in the clarification and simplification that results from teaching new knowledge to graduate students, and in the rapidity with which the number of recipients of this new simplified knowledge grows by teaching it to undergraduates.

There is only one way an engineering school can provide an undergraduate education that will convey the ideas proposed and explored by the pure scientists, that will develop and extend these ideas and reduce them to the point at which they can be efficiently exploited for use by mankind. It is multipronged. It means first a close association between faculty and students in research; second, a strong program for teaching advanced concepts in graduate courses; and third, an engineering faculty that is enthusiastic about integrating these ideas into new meaningful forms and teaching them in a coherent and stimulating manner to undergraduates.

The task of achieving a cohesive purposeful curriculum is inherently complex, because the flow of new knowledge is inherently downward, from research through graduate teaching to undergraduate teaching, whereas the student moves in the opposite direction from freshman to doctor. A major program to modernize, strengthen, and deepen undergraduate teaching relocates much graduate material in undergraduate courses. This cuts the heart out of many graduate courses. As the studies of the early undergraduate years are strengthened, those of the upper-class years no longer provide either the challenge or the learning of knowledge

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that is enduring. Thus we immediately see that the whole program in engineering must be continually remade to give it a new kind of unity, continuity, and enduring negotiability. The concept of concentrating on fewer common-core curricula for undergraduate study in engineering, with professional work being held for graduate work, is gaining acceptance.

Because the rebuilding of graduate courses must be performed round knowledge generated in research, graduate teaching should be done only by those who do research. This rebuilding necessitates the establishment of new facilities and new themes for open-end research that will be pertinent to the needs of society in the next ten or twenty years. It periodically necessitates a major shift in the emphasis of a professor's efforts, with the result that he must accommodate to the chronic pain of mastering new ideas. To say it bluntly, he must be retreaded. But he must also be retooled, for, to engage in frontier research, he needs a vast array of new facilities that are not only expensive, but for many fields of modern engineering also require a somewhat special type of staff.

The problem of strengthening the engineering curricula in many American colleges presents what I believe to be a dilemma,[7] for the present wide-scale activity to increase the science content of such curricula can, if not skillfully done, result merely in teaching science to engineers and not in teaching the engineering of science. As the core of the curriculum becomes more strongly based on science, it invariably becomes more abstract, and professors increasingly need teaching aids to help students gain a good physical grasp of these abstract ideas. Furthermore, they are often in a quandary to provide worthwhile engineering examples or to engage in sophisticated projects that will tax the latent engineering power of the more fundamental learning. A student is not encouraged to master difficult concepts if he is asked to apply them only to the solution of trivial problems. The real task before professors is to devise appropriate versions of modern working science—to couple knowledge of the disciplines of physics, mathematics, and chemistry with new engineering frontiers.

It is this frontier interaction in engineering which an engineering professor should teach students intending to become engineers and not scientists. It is not the responsibility of a science professor. We could make no more drastic mistake than merely to recreate the engineer in the image of the scientist or to inculcate in engineers a habit of being overly preoccupied with analysis to the subordination of

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purposeful synthesis. Ways must be found to develop new unified themes of applied science and to supplement them with engineering examples of their exploitation in order that our students of tomorrow acquire judgment and intuition for what is new and meaningful and how to exploit it. Hence, I use the words, *the engineering of science*. The trouble is that to do these things our professors must acquire a great deal of new knowledge; they must move up to the frontiers of engineering, they must play the role of prophets. For many, this will be a new task, one that calls for a host of new facilities. For the nation as a whole, it is a challenge of great magnitude.

As examples of some of the problems, we note that the most advanced developments in theoretical physics, such as quantum mechanics, have now become working tools in many engineering fields but not in enough engineering curricula. The new, abstract, and rapidly emerging field of information theory is influencing the designs of many communication systems. The capabilities of today's electronic computers (let alone tomorrow's) have made analytical methods more fruitful and have changed the relative importance of various branches of mathematics for engineers, whether they work in laboratories, in design, in production, or in business. But many professors in engineering schools have yet to solve their first problem on a digital computer. Too few have begun to refocus their teaching so that students can benefit from what computers can do. As computer capability is exploited, a deeper insight into the fundamentals that underlie the problems computers can solve becomes increasingly important. Seldom do the problems offered students present a true picture of the broad decision-making responsibility they must eventually accept, and rarely are either students or professors equipped to exploit the capabilities of computers in these complex situations.

It is not sufficient merely to strengthen and teach isolated packages of the classical engineering sciences, such as thermodynamics, fluid or solid mechanics, electromagnetic theory, and so on. To make clear the aspect of frontier coupling, new syntheses of quantum mechanics, statistical mechanics and the postulates of classical thermodynamics oriented toward materials and modern energy-processing systems (involving, for example, solid-state devices and plasmas) must be achieved. We must then provide students with some insight into practical engineering examples.

Since liquid helium has become widely available, many engi-

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neering students can be introduced to cryogenics, to masers, and to parametric amplifiers. They can then look into the golden age that lies ahead if they come to grips with the new field of molecular engineering. They will learn how the properties of matter arise, how they can be made to order, and how new materials can be formed into new combinations for energy processing and communication systems. Here we perceive a vast area of technology that must be clarified, sharpened, and appropriately packaged for engineers. Engineering students will require teaching laboratories in which they can obtain a more profound understanding of the microscopic nature and the modern properties of materials. I emphasize that the need for tomorrow is not necessarily to strengthen (which most often means to fatten) today's designation of the engineering sciences, but to find the innermost core of interdisciplinary technology and spell it out clearly. We have yet to begin to do this.

What we want are so-called basic courses that give purpose to learning, that provide meaningful presentations, so that our engineers can integrate and employ all segments of technology and acquire skill in weaving a host of seemingly unrelatable concepts into the total fabric of tomorrow's engineering world. I wish to emphasize the word *purpose*. Our ambition should be to put purpose into the life of the youth, to give them a picture of the great vistas of the future, to try to deepen and intensify their thirst for knowledge, so that they will have some picture of the horizons of the world they are to live in.

If we can perceive, even dimly, some vision of these new horizons, and if we attempt to build an educational program in engineering that appears likely to prepare a young man for effective participation in these emerging fields, we will have maximized the probabilities that these visions will become realities. Our job, and the dilemma, is to bring this objective into the classroom and the teaching laboratory. Therefore, we need to think in terms of new horizons for engineering and new goals for engineering education.

Some New Horizons

I can see the horizons for the new engineer emerging from a broad appraisal of the engineer's basic motivations.[8] I suggest that we focus our attention on four basic needs: communication, energy exploitation, materials, and mobility. Man must communicate in order to live. To project a student's vision beyond what are essentially closed-

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end instruments of communication (such as the radio, the telephone, or the computer), I suggest that we point out the open-end nature of the concepts that underlie the processing, storing, and transmitting of information between man and man, man and machine, machine and machine. This broad point of view opens up new horizons that offer engineers a greatly enhanced role in society. Perhaps most importantly, we should stimulate the engineer to direct some of his skills toward achieving a better understanding of the data processing systems within man. It is clear that, as a student masters the specifics of this point of view, he will work with the radio, the computer, the control system. We must help him appreciate that today's man-made communication systems are primitive compared with those occurring in humans, but that they serve as important springboards toward a better understanding of human beings. Especially in the field of automation (as evidenced by the recent interest in adaptive control), there is now a need for interaction and communication among the physical, social, and life sciences and the humanities.

Second, man has an ever increasing need to exploit energy creatively. Society needs engineers who can not only provide improved conventional energy systems but also bring about the synthesis of modern science that will yield unconventional developments of our energy resources. All students should be exposed to the open-end concept of energy processing, rather than being preoccupied with such devices as motors, boilers, turbines, and generators. Controlled thermofusion energy, or the practical exploitation of photosynthesis, or plasma-energy converters will be a long time in coming if scientists and engineers remain compartmentalized. Engineers must have an environment in which, in collaboration with the scientific leaders of tomorrow, they can learn what the new syntheses should be.

Third, we note that neither man's need to communicate nor his need to exploit energy can be satisfied unless he understands better the materials of the world in which he lives. He has only the elements of nature with which to work. He must be given an imaginative understanding of the invisible and visible properties of matter and taught how they can be put together in ways heretofore unrealized. On every front man has overtaxed the capabilities of modern materials to perform the role that the foreseeable future imposes on them. New applications of scientific principles must be brought into being and used by engineers to achieve a more profound understanding of the properties of materials. In this way we can bring about undreamed-of improvements in assemblies of matter to pro-

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vide materials that can be worked into new structures and machines for the future.

Finally, man has always been striving for greater and greater mobility. Not only does he need mobility for himself; he must move materials from one part of the world to another as his industrial machine becomes more truly his slave and not his master. Instead of programs that permit students to become preoccupied merely with highways or the automobile or the airplane, we must have programs that will comprehend the whole problem of transporting goods and people, by sea, land, and air. The open-end topic of mobility unfolds a wholly new dimension to the role of tomorrow's engineer.

The Emergence of Research Centers

Interdisciplinary research centers are becoming an integral part of the research and teaching facilities of a number of universities and engineering colleges.[9] At my institution the last decade has seen the establishment of the Center for International Studies, the Research Laboratory of Electronics (sponsored jointly by the Departments of Physics and Electrical Engineering), and the Center for Urban Studies. Currently, plans are under way to establish five new centers to embrace interdisciplinary themes, four of which will materially enhance the education of engineers. These four are: the Center for Communication Sciences; the Center for Materials Science and Engineering; the Center for Aeronautics and Astronautics; and the Center for Earth Sciences. In addition, members of the faculty whose interests focus broadly on the field of energy processing are generating a center by voluntarily federating in ways allowing them to share the decision-making responsibility for their activities. With this comes a significant strengthening of their resources and a quickening of their advance toward many new horizons.

This federating or regrouping across traditional departmental lines does several things: it quickens the exchange of new knowledge by bringing together workers in related areas, so that they can exchange ideas directly instead of through the much slower avenues of publication; it extends the freedom of a professor because he may simultaneously be identified with his department and with one or more centers; it greatly augments the facilities available to each participant for the conduct of research; and it enables both staff and students to seek out more readily the leaders in these new areas of interdisciplinary thought, who previously were so widely dispersed

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throughout the Institute that they were rather difficult to identify.

New interdisciplinary themes of knowledge that lead to competence in new fields are taking definite form and are already penetrating undergraduate education. The themes themselves exhibit great viability and a powerful potentiality for the self-generation of new engineering opportunities. Today's undergraduates, who have a knack for seeking out areas which they think will become important, exhibit a strong affinity for the study of these new themes. As this situation matures, it is possible that new curricula will appear and that new departments and new academic degrees will be established.

The Engineering Point of View

The work of devising practical configurations of materials and devices that industry can exploit and market and that people can use is engineering in the purest sense. In many of its aspects it is an art, and there is abundant evidence in engineering practice that its efficient accomplishment necessitates a project type of organization.

For these reasons, departments within the School of Engineering at the Massachusetts Institute of Technology are developing educational project-type laboratories hand in hand with the evolution of the research centers. In these project environments exacting and authentic examples of design can be made manifest. For example, projects directed at the development of new configurations of memory, new logic systems, or improved input-output equipment of computers may be undertaken by faculty who are simultaneously members of the Center for the Communication Sciences. Likewise, projects directed at exploring the many new problems to be solved in achieving energy-conversion systems exploiting magnetohydrodynamics, plasma diodes, or thermo-electric converters of heat to electricity may be undertaken by faculty who share membership in the Center for Materials Science and Engineering or in the group working on energy sciences. Here the art of doing engineering in authentic ways can be given expression in forms that are compatible with the role of a technical university.

For the future we foresee, on the one hand, groups of faculty working in the research centers on broadly based themes of knowledge which, from the viewpoint of engineering, are the engineering sciences, and, on the other hand, the same professor or a colleague

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working on design or end use as an expression of his talents and interests. At the present stage of our evolution it appears that the project activities can best derive their direction from their appropriate departments.

As colleges devise procedures by which students, undergraduate as well as graduate, can serve as interns in these project-engineering laboratories, the purposefulness of engineering as contrasted with the goals of the scientist can be made clear. Insight into the work of conducting genuine design can be learned by seeing it done under the guidance of a master. The art of compromise and approximation that is the essence of engineering can be made clear in ways that heretofore have been achieved by the few and that are now needed by many.

To achieve these new goals, I believe that many academic changes must take place. To document and present the technical advances to the next generation of engineering leaders, a new kind of faculty must emerge. To bring this new faculty into being, many of today's professors must undertake much new learning, and many new men must be added; they will inevitably be younger. The older man must still be on the team; he can bring the warmth, the human understanding, the ethics and patience required of engineering, but to be effective, these qualities must not be fastened to an old point of view. The older professor must always strive to minimize his own technical lag, and to do this he must be given support.

The environment in which this new faculty man is to operate must be free of the compartmentalization that our heritage has produced. Wholly new groupings of interdisciplinary scholars must be planned in order that the cross-fertilization of knowledge can occur and the new synthesis be documented. Specifically, the challenge of today is to integrate the areas of physical science, life science, engineering science, social science, and the humanities, in ways that provide a core of knowledge that does not now exist. Procedures for teaching this core must be devised. New teaching aids and new laboratory facilities will be needed.

The scope of this paper has been limited deliberately to the scientific and professional aspects of engineering education. The place of the humanities, the social sciences, and the life sciences in the education of an engineer will be even more important in the future, and the task of integrating these elements into engineering education must progress in parallel with the development of the technical

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program. The changes in the professional program advocated here are intended to increase the capacity of the engineering student to assess the social, political, and economic consequences of his actions. They should also serve to increase the role of cultural interests in his life. Beyond this it may also be observed that any engineer trained broadly in the principles, in the theories, and in the highest creative expression of his own field will tend naturally to act as a liberal influence in his community. His attitude toward himself and his profession, his capacity to proceed from the particular to the general, and his training in establishing connections between things not superficially relatable, will naturally tend to give him a broader sense of proportion and to make him a truly civilizing influence in the society of which he is a member.

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GERALD HOLTON

Scientific Research and Scholarship
Notes toward the Design of Proper Scales

THE FACT THAT an important social invention has occurred, one that is destined to transform a part of society, sometimes goes unrecognized for a surprisingly long time. A case of this sort was the nineteenth-century development of science as a small but worthy profession for individuals in its own right. Another case exists at present. It is to be found in the particular way by which scientists have come to organize and coordinate their individual research pursuits into a fast-growing commonwealth of learning.

The new pattern for doing basic research in science is worth studying for its intrinsic merits. This essay hopes to spell out what it now means to be active in basic scientific work; but it should also help to explain coherently individual elements of contemporary science, each of which is obvious enough by itself—the rate and excellence of research output, the size of the funds that are needed or made available, the spectacular applications of science in industry and the military establishments, and so forth.

There are more important reasons still for sketching here the apparent operations of this commonwealth of learning. One reason is the fact that this pattern carries specific lessons for the conduct and organization of effective scholarly work in any field, no matter how different or remote from science it may be and must remain; one such lesson should be in the definition of a scale for measuring the adequacy of support. The second reason is, conversely, the realization that scientific work may best be understood as one of the products of the general intellectual metabolism of society, and hence that in the long run the growth of science depends critically on the growth of all fields of scholarship. This interpretation (to be published separately) has specific implications for policy, particularly in the humanistic studies.

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Thus I deal here with two related preconceptions involving science: first, that its spectacular efflorescence is the result of forces so unique to science that other fields cannot hope to apply its lessons to their own benefit; and second, that science in turn is nourished by a system of its own whose health does not depend significantly on the state of all other scholarship. Both these conceptions are false.

The Stimuli for Growth

As a profession, science has been remarkably little studied, except for a handful of books and reports that seem to be covered over by the growing flood of changing statistical data. I shall choose basic research in physics as carried on today in the United States to characterize some common features of all the sciences. The choice is quite appropriate from several points of view. For example, the number of its academic practitioners has not grown at an inordinate rate compared with other fields of study. In the year 1914 there were only 23 doctorates awarded in physics in the United States out of a total of 505 for all fields, 244 of which were in science.[1] Thus some fifty years ago the Ph.D. degrees granted in physics amounted to 4.6 percent of all Ph.D. degrees for the year, or 9.4 percent of those in all the sciences. Remarkably enough, the most recent year for which good figures are available, 1959, shows virtually the same proportions. The 484 Ph.D. degrees in physics accounted for 5.1 percent of all Ph.D. degrees, and for 9 percent of all those in science.*

The great rise of research output in physics in the last half century did not entail a corresponding loss of numbers in other areas. Indeed, in a sense, there has been a relative decrease in the number of basic-research physicists, since now one-half of all new Ph.D.'s in physics are heading for governmental or industrial research and administration employment for which there was no equivalent in previous years and where a much smaller fraction of men are doing basic research than are in academic employment.[2] Thus the remaining group of Ph.D.'s in physics is of intermediate size—that is, it is comparable to the graduating Ph.D. classes in history, political science, mathematics, religion, or English literature.[3] Those who do not stay in the academic life serve, of course,

* *Statistical Abstract of the United States, 1961* (82nd edn.), pp. 130, 539. The total number of Ph.D. degrees in science in 1959 was 57 percent of all Ph.D. degrees versus 48 percent in 1914—a noticeable but not unbalancing shift.

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to link physics to applied science, as is also the case in the larger fields of chemistry and biology.

Physics is a good profession to choose for this analysis because there exists an immense variety in the group, from the man in the small college who, with two or three colleagues, does all the work of the department and still finds time to think about new physics, to the man whose full time is spent in the laboratory of a large research institute. Any two physics-research projects picked at random are likely to have less in common with each other than does the statistical average of all physics research compared with the statistical average of almost any other experimental science. And yet there is in this group, taken as a whole, a strong sense of cohesiveness and professional loyalty. Despite the variety, despite the specialization that makes it difficult to follow what is being done in the laboratory next door, despite the important differences between basic and applied, large and small, or experimental and theoretical physics, its practitioners still clearly conceive of themselves as doing in different ways work in one identifiable field. There are no large cleavages and disputes between sizable factions representing fundamentally different styles.

If we first focus specifically on the professional life of a representative physicist, it is essential to remember at the outset the brevity of time in which basic research on a significant scale has been done in this country, or, for that matter, anywhere. The word "scientist" itself did not enter the English language until 1840. Until about the turn of the century, the pattern was that of work done by isolated men. Experimental research was often financed with one's own funds. Even in a relatively large department, advanced students were rare. Thus, Harvard University, one of the earliest in the United States to grant Ph.D. degrees in physics, had a total of six theses before 1900, and thereafter an average of about two per year until World War I. During that war, it has been reported, "there was no classification of physicists. When the armed forces felt the need of a physicist (which was only occasionally), he was hired as a chemist."[4] Having an adequate laboratory space of one's own in most universities was an unfulfilled wish even for the outstanding experimentalist—though this applied more to Europe than to the United States. For example, in 1902, at the peak of their research, four years after their discovery of polonium and radium and after many years of pleading for more space in which to do their extensive chemical and physical work, the Curies still had only their old

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wooden shed at Rue Lhomond and two small rooms at Rue Cuvier. On being proposed for the *Légion d'Honneur*, Pierre Curie wrote to Paul Appell: "Please be so kind as to thank the Minister, and inform him that I do not feel the slightest need of being decorated, but that I am in the greatest need of a laboratory."

The growth of science between the wars needs little discussion. The driving force was in part the needs of an increasingly sophisticated, technologically oriented, competitive economy, and in part the sheer excitement induced in more and more students (drawn from a widening base in the population) by beautiful ideas ever more rapidly revealed, such as the quantum theory and early nuclear physics. But the rate at which exciting ideas are generated is correlated with the ability of a field of study to "take off" into self-amplifying growth.

To the economic and intellectual stimuli of earlier days the Second War added the new stimulus of the threat of power in the hands of the Germans, who had been the foremost nation in scientific achievement. Einstein's letter of 1939 to President Roosevelt (so like that of Leonardo to Sforza!) dates the moment after which the scale of research support changed in a surprisingly short time by more than an order of magnitude. Since 1940, Federal funds for science alone have grown over one hundred-fold.*

What mattered here, however, was really not so much the hot war and the cold war, for wars by themselves had not in the past unambiguously promoted the growth of science. Rather, it was a development unprecedented in recorded history: the demonstration that a chain of operations, starting in a scientific laboratory, can result in an event of the scale and suddenness of a mythological occurrence. The wide-spread fascination and preoccupation with science—in itself an essential element in its continued growth—find here their explanation at the elemental level.

In our society there had always been a preoccupation with the scientific hero who comes back with a major revelation after having wrestled with his angel in self-imposed isolation (Newton, Röntgen) or in relative obscurity (Curie, Einstein). Now, a whole

* Great care must be taken not to use any easily counted measure (money, persons, pages of articles, energy of accelerated particles) to stand for increases in what really "counts," namely, in the qualitative understanding and the qualitative rate of increase of that understanding. The numbers are useful to a degree, but the effects of numerical increases in hands, minds, and tools for science are highly nonlinear.

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secret army of scientists, quartered in secret cities, was suddenly revealed to have found a way of reproducing at will the Biblical destruction of cities and of anticipating the apocalyptic end of man that has always haunted his thoughts. That one August day in 1945 changed the imagination of mankind as a whole—and with it, as one of the by-products, the amount of support of scientific work, including accelerators, field stations, observatories, and other temples.

To a physicist, nothing is so revealing as relating qualitative changes to quantitative changes. Man can cope surprisingly well with large rates of change in his environment without himself changing significantly. His psyche can take in its stride rapid rearrangements in the mode of life—collectively, for example, those owing to a large increment in the life span, and, individually, those owing to great deterioration of health. Precipitous changes of condition during quite short periods are well-tolerated. But the traumatic experience of *one* brief, cataclysmic event on a given day can reverberate in the spirit for as long as the individual exists, perhaps as long as the race exists. Hiroshima, the flight of Sputnik and of Gagarin—these were such mythopoeic events. Every child will know hereafter that "science" prepared these happenings. This knowledge is now embedded in dreams no less than in waking thoughts; and just as a society cannot do what its members do not dream of, it cannot cease doing that which is part of its dreams. This, more than any other reason, is the barrier that will prevent scientific work from retreating to the relative obscurity of earlier days, even if some turn in our civilization should bring all other phases of our lives back to their earlier levels.

Who Are the Scientists? A Representative Case

The element of discontinuity in the general experience of our time merely reinforces the discontinuities in the experiences of contemporary science. The rate at which events happen is again the important variable. For, when a field changes more and more rapidly, it reaches at some point a critical rate of activity beyond which one has to learn by oneself, not merely the important new ideas, but even the basic elements of one's daily work. This is now true of many parts of physics and of some other fields of science, not only for the most productive and ingenious persons, but for anyone who wishes to continue contributing. The recent past, the

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work of one or two generations ago, is not a guide to the future, but is prehistory.

Thus the representative physicist is far more his own constantly changing creation than ordinary persons have ever been. His sense of balance and direction cannot come from the traditional past. It has to come from a natural sure-footedness of his own—and from the organism of contemporary science of which he strongly feels himself a part. None of the novels or the representations in the mass media which I have seen have portrayed him with success, perhaps because they missed the fact that this is the component that really counts.

Though I am referring to statistical data, the man I have selected to typify my comments is not a statistical average but rather a summary of traits, each of which is well-represented in the profession and all of which, taken together, will be generally agreed to among physicists as representing a worthy and plausible specimen. I go into some detail, partly because not only the novelists but even the anthropologists have so far failed to penetrate this part of the forest to provide a good description of the new tribe. But I also want to make a basic point about the humane qualities of training and professional life. First of all, I note that our man, like the majority of his colleagues, is young, perhaps thirty-five years old, or just three years short of the median age of fulltime-employed scientists in the United States.[5] Even so, he has already had nine years of professional experience and increasingly creative work, having finished his thesis at the age of twenty-six, after a study period of about four and a half years.[6] In completing this work, like 25 percent of all physics graduate students in the country,[7] he was supported by fellowships, in his case by National Science Foundation fellowships for the first two years.* During his last two years he worked on a research assistantship, helping an experimental group in the construction of a new type of beta-ray spectrometer and submitting as his thesis early measurements he made with it in connection with this work.** Thus, like the majority of graduate students in physics,

* The present number of such National Science Foundation awards for graduate study, offered in all the sciences, is 2,500, at stipends of $1,800, $2,000, and $2,200 for successive years, plus full tuition, a family and travel allowance, and a cost-of-education allowance to the institution; in addition, there are a number of other substantial fellowship programs in science.

** More than one-third of all graduate students in experimental or theoretical physics held research assistantships in 1959-1960, and 31 percent were holding teaching appointments while studying. This, with fellowships and

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his education was financed from the outside and proceeded without significant delays.

After graduation, he hoped to obtain a postdoctoral fellowship—perhaps the best way for the really good scholar to consolidate his grasp of his material and to map out a field for himself before plunging into the routine of professional life. But there are not yet enough such programs, and he did not receive an award. He therefore chose among the two or three suitable offers of a job and went into a middle-sized university. In selecting academic life—the only aspect of the profession to be treated here—he has become one of approximately 8,000 physicists in colleges and universities, as against twice as many working in industry and half as many in the government.[8]

He knows the pull toward industry to be strong because he compares offers that regularly reach him. The present median income for all college and university physicists of his rank and approximate age is $8,000[9] (somewhat better in his particular case), whereas the median income in industry is $3,000 higher,[10] and the usual offer he receives from industry is higher than that. Moreover, the pull may be expected to be much stronger over the next years. While the needs for physicists in educational institutions and in the Federal government are expected to grow by 66 percent respectively, the figure for industry is 130 percent.[11]

These facts help to explain his lack of deep concern as to whether the forthcoming discussion of his promotion to a post having tenure in the present university will go well. He knows from folklore that fifteen years ago there were only a few really good departments of physics in the United States; but now there are some thirty universities with research programs lively enough to yield between five and forty-three theses each year,[12] and there are many more good small departments. The availability of funds has helped to spread excellence in basic research widely and rapidly. He would have an even larger choice in liberal-arts colleges, but he has become rather used to cooperative experimental research of the size and with the tools that are usually associated with the larger universities. Significantly enough, there are twice as many physical scientists on the faculties of universities as in liberal-arts colleges; they form a larger fraction of the total faculty on campus; and—most important for this par-

scholarships, means that only a relatively small fraction was not helped one way or the other, though 30 percent reported that inadequate finances were still a retarding factor in their graduate work. Source: Interim Report, Ref. 6.

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ticular experimentalist—whereas the average liberal arts college employs one nonfaculty professional staff person in physical science for every ten physical-science faculty members, at the average university the proportion is better than one to one.[13] This implies much better backing from technical personnel in universities, particularly for those inclined to do large-scale experimentation; however, this ratio will probably soon improve, when the regional joint facilities now being developed among colleges in several areas are completed.

Our physicist has to his credit a number of publications—several short papers and one long review paper. He is considered a productive person, interested in one of the main excitements (which to him has recently become an experiment in the field of high-energy physics), and, to some degree (less than one would perhaps like) in his undergraduate students. These he meets relatively rarely by the standards of his predecessors. One course, more rarely two, is a typical class schedule for a physics professor at a major university; it allows sufficient time for work, for contact with graduate students, and for the long seminars with colleagues in which one carries on one's continuing self-education. For the same purpose, his research leaves, sponsored by one of several national programs, come rather more frequently than sabbatical years used to do. Summers are given by the members of his small group to research on the same contract with the government agency that sponsors the project. During these months there is extra salary for faculty and assistants. When necessary, there are trips to one of the seven major laboratories sponsored by the Atomic Energy Commission but administered for unclassified academic research by a regional group of universities.*

These circumstances, to repeat, are not typical of all scientists, but representative of a type of new scientist now often encountered. What is emerging is the picture of a research-minded scholar who lives in a world that has arranged fairly adequate support to help him carry through his ideas wherever such help is possible.

* One example is the Brookhaven National Laboratory, where approximately half the operating time of the principal accelerators is reserved for the resident staff, and the rest is for visiting groups from universities and other domestic and foreign institutions. The present budget of the Brookhaven National Laboratory is $18,700,000; the total budget for all seven such laboratories in the United States for the next fiscal year is $135,000,000. (See *Background Information on the High Energy Physics Program and the Proposed Stanford Linear Electron Accelerator Project.* Report of the Joint Committee on Atomic Energy, 87th Congress, 1st Session, 1961, p. 38.)

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This help shows up in a number of other important (or even quite trivial) ways. For example, postdoctoral fellowships bring good research talent at no extra cost to the project, for a year or two at a time. Or when an important-looking article in a foreign-language journal appears (one not among the many journals regularly translated by the American Institute of Physics and other organizations), funds for a translating service can be found.

Our physicist's current research grant happens to have been negotiated with the Office of Naval Research, after some extended discussion and troubled waiting. An insight into the sources from which basic-research sponsorship usually comes and the places where the work is done may be obtained by a quick count of the acknowledgments cited in the program abstracts for the most recent meeting of the American Physical Society.[14] Of the 480 papers contributed, 18 percent are from colleges and universities without indication of foundation or government support; 43 percent acknowledge such support (from the Atomic Energy Commission, the United States Air Force, the United States Naval Research, the United States Army, the National Science Foundation, the National Aeronautics and Space Administration, or others); 21 percent are papers on basic research done in and largely financed by industry; 16 percent were done in government (including national) laboratories by persons employed there; and the remaining 2 percent include sponsorship from private foundations such as Sloan and Ford.

Our man's Navy-sponsored contract, therefore, is financed quite typically; it is not a large contract, and of course no part of the work is hampered by restrictions on publication nor, indeed, does it have any directly foreseeable applications to Navy activities.* The amount of the grant available to our man and to a senior colleague and collaborator who is acting as "principal investigator" is perhaps $46,000 for a two-year period. About half this sum is for the purchase and construction of equipment; the rest is largely for serv-

* Basic-research sponsorship by the Navy, Army, Air Force, Atomic Energy Commission, and other branches of the government (and in other countries by their equivalents) is generally justified in such terms as these: the project is one "with which the Navy should be in communication lest a breakthrough of vital importance occur. A classic example of the latter was early Navy work in nuclear physics which ultimately permitted more rapid utilization of nuclear power for ship propulsion. It is not possible to define firm boundaries as to Navy interest because of the unpredictability of basic research results and the complex interrelationships between fields of science." (*Basic Research in the Navy*, vol. I, p. 53.)

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ices, including graduate-student research assistants. Though the Navy cut down the original request for funds, there is still enough for the machine shop, electronics technicians, secretarial help, work by the draftsman's office or the photographer, and for publication and reprint charges. The contract support, therefore, is adequate.

Our physicist is better off than a considerable number of other academic physicists in less convenient circumstances. Many, in smaller colleges particularly, are hard-pressed. And, on the other hand, this man is perhaps not differently situated from many an equally talented and productive young man or woman in fields outside the sciences. Nonetheless, it is clear by the standards of the recent past in physics itself that here is a new type of scholar. Indeed, he and each of many colleagues like him has available for life the security, means, and freedom to do research that Alfred Nobel hoped to give by his prize to the few outstanding persons in the field. Most significantly, our new scientist is new in that he does not regard himself as especially privileged. The facilities for doing creative work are being accepted and used by him without self-consciousness and with the same naturalness as one accepts the convenience of a telephone.

This is the point. For whatever reasons, right or wrong, that society has chosen to make this possible, the circumstances exist for getting scholarly work done by more people than might otherwise do it, and for providing humane conditions of training for the oncoming generation.

There is at once a number of urgent objections, of course. One might say that it is not difficult to construct utopias for any field, given enough money. On the one hand, the money involved is easily afforded, the amount small on any scale except that of depression-reared experience or the starvation-oriented practices in all too many other equally worthy fields of scholarship;[15] on the other hand, this is not a paper utopia, but a working system for employing people's minds and hands in the time-honored mission of adding to the sum of the known.

Alternatively, the opposite objection may be heard: that really good ideas do not flourish without an element of personal hardship. But, despite the support intended by well-known stories (true, false, and sentimentalized), the evidence now is altogether the other way round. The once-in-a-generation ideas may still, as always, come from the most unexpected places; yet, throughout history, trans-

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forming ideas, as well as great ideas only one magnitude less high, have not appeared in science at a rate equal to a fraction of the present rate. The sacrifice implied by the sum of thousands upon thousands of wretched student and research years under inadequate conditions in the past can surely be no source of satisfaction, even if the additional expenditures had not, after all, shown a better yield in science. I suspect that another Marie Curie, a Kepler, even a Roger Bacon, would not be damaged by more help, or by the availability of cooperative research facilities for those inclined to use them.[16]

There remains a third major objection. Has this useful and often pleasant arrangement not been bought at too high a price? It is popularly suspected that somewhere in the background there is a group of high military officers whose interest and decision ultimately control, from year to year, whether or not academic research shall flourish, just as the Renaissance patron determined whether the studio would continue or not. If tomorrow it were discovered how to destroy multitudes by reciting poems, the physicists would have to move into the garrets, and poets would be enticed into the laboratory space. It is not, after all, only the intrinsic merit of the subject that now gives it vigorous life, but also the weapons-aspect of its occasional by-product, vigorously exploited by applied scientists and engineers in industry and government. As the student newspaper, *The Tech*, at the Massachusetts Institute of Technology said not long ago in a plaintive editorial: "Most of the students at M.I.T. will, at some time in their lives, work for the government on military projects."

This is of course frightening and confusing ground. In part these widely held conceptions are not true, or at least no longer true. The influence of government (particularly that of the military branch) on science has not been without an effect in the opposite direction. As some scientists have become increasingly effective and trusted in their roles as advisors, a noticeable educative influence has made itself felt in Washington. The rising role of certain agencies such as the National Science Foundation and the National Institutes of Health have vastly improved the picture in the last decade. The research effort, when carried on above a certain minimum level, becomes an autonomous part of the system, as certain long-resisting industries are also beginning to discover. Even if any group now wanted to turn off the Federal support of science, it could not be done. On the contrary, it is nowadays more typical for scientific

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advisors to try to turn off what appear to be hastily conceived projects initiated by the Pentagon.

And yet, the deeper intent of the objection cannot be either disproved, or evaded, or sustained. It is at the same time bitterly true and false, as would be a refusal to sanction the rising standard of living in our present, artificially sustained economy. The problem posed is at bottom the same for the academic scientists as it is for anyone from grammar school teacher to legislator who participates in the life of a nation which is so closely geared to an arms race with a determined antagonist. And while the hope of gaining indirect or long-range benefits from basic science motivates those agencies that support physics, the large majority of academic scientists themselves have clearly declared again and again their eagerness to work toward a peaceful resolution of the crisis that is to a degree responsible for the high level of their support. In fact, it is largely from the work of such scientists that one may hope for the development of ideas, understanding, and techniques that will help in achieving what mankind never before took to be a serious task, the control of armaments and of inter-national aggression.

Requirements for Growth
Mobility, Organization, Leapfrogging

While it would not be either possible or necessary in this context to describe in detail the research project that engages our physicist's attention, let us turn from his personal background to the general rules of action of the profession. We leave him as he is contemplating a possible modification in the use of a liquid-hydrogen bubble chamber, a device for making apparent the passage of elementary particles such as those generated in accelerators. The triggering event for this thought was a brief article, the heading of which is duplicated in Figure 1.

It will be instructive to study this figure with care. It contains a great deal of information about the metabolism of a lively field of scholarship, denoted even in the very name of the journal. The *Physical Review* is perhaps *the* definitive physics journal in America, though it is only one of the many good journals in which basic research in physics is published. In 1958, the sheer bulk (7,700 pages in that year), the continuing rate of expansion, and the delay between the receipt and publication of articles made it necessary to detach from the *Physical Review* the "Letters to the Editor," in

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which brief communications are made. This resulted in the separate, quickly printed, semimonthly publication, *Physical Review Letters*. The article indicated in Figure 1 came out a month after its receipt; under the older system it might have taken twice as long.

VOLUME 7, NUMBER 6 PHYSICAL REVIEW LETTERS SEPTEMBER 15, 1961

HELICITY OF THE PROTON FROM Λ DECAY*

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Figure 1. The heading of a short announcement of results in *Physical Review Letters*, 1961, 7: 264.

Why is this speed so important? One explanation could be that this profession is made up of fiercely competitive people. It is true that egos are strong and competition naturally present. But in the United States, at least, it proceeds in a low key; personal relationships, though perhaps lacking some color and warmth, are almost invariably friendly.

There are three explanations for this fact. First, the authority of scientific argument does not lie in personal persuasiveness or in personal position but is independently available to anyone. Second, there is the general loyalty to the common enterprise, mentioned previously. And most importantly, scientists as a group seem to be self-selected by a mechanism that opposes aggressive competition. Anne Roe, in summarizing her long studies in this field, reports in an essay, "The Psychology of Scientists,"[17]

Their interpersonal relations are generally of low intensity. They are reported to be ungregarious, not talkative—this does not apply to social scientists—and rather asocial. There is an apparent tendency to femininity in highly original men, and to masculinity in highly original women, but this may be a cultural interpretation of the generally increased sensitivity

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of the men and the intellectual capacity and interests of the women. They dislike interpersonal controversy in any form and are especially sensitive to interpersonal aggression.

Thus the theory of aggressive competition is not likely to be correct in explaining the speed often felt to be necessary. Rather, one must look to other causes. I will select two quite obvious ones, which seem to me among the most important. One is the intense interest in what has been found. The other is the natural desire not to be scooped by other groups known to be interested in the same topic. And here it is important to note a major cause for this possibility—the fact that research is usually carried out in the open. It would be inconceivable for a typical academic physicist not to instruct any visitor who shares his interests on the detailed current status of his research, even if, and precisely because, this same visitor is working on the same "hot" lead. This principle of openness is one of the basic aspects of the scientific ethos.

We now read the names of the authors given in Figure 1, and are perhaps surprised by their number. To be sure, a commoner number of collaborators would be two, three, or four, although ten percent of the authors of the other papers in the same issue of the journal are sole authors. Yet it is neither the longest list of authors to be found, nor is it unrepresentative. Here let me signal three points. One is the cooperation in research that is implied within each group, as well as among widely dispersed groups; another is the distribution in this country (and indeed internationally) of the cooperating enterprises (some long established, others not known as little as twenty years ago to have had strong research interests in physics); the third is the authors' remarkably heterogeneous backgrounds that are implied. The list of names makes the point more bluntly than could any comment of mine.

This last point is perhaps the most important of these factors in explaining the growth of science in our time. Nowhere else can one find a better *experimental* verification of the general worth of the democratic doctrine, which is often uttered but rarely tested seriously. Social and geographic mobility in a field of work, as in society itself, is the essential prerequisite for a full exploitation of individual talent. The success of contemporary science all over the world despite the great variety of social and political settings is merely a striking case study of this proposition.

It is somewhat ironical to note how the need for talented individuals in science is discussed by people who speak about it in very

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different ways. For example, Academician A. N. Nesmeyanov, president of the Soviet Academy of Sciences, said in closing a celebration on the first anniversary of the launching of Sputnik: "We may be confident that in the name of the great ideals of humanity, our people, under the leadership of the Communist Party, will accomplish new and ever more notable feats. Our guarantee of this is the socialistic structure of our country, which gives wide rein to the development of science and ensures the bringing out of the notable talents of our people."[18]

This comment was cited by L. V. Berkner,[19] president of Associated Universities, Inc., which administers the Brookhaven National Laboratory. He added: "We have one great advantage, and that is the immense freedom that is enjoyed by each of our citizens. This freedom challenges the individual, without being pressed by his government, to do his part in bringing the free society of men in which we live to a position of unquestioned leadership. For in a free system, it is the individual, not the government, that determines the competence of the system."

The important fact is of course that regardless of their deeper differences the two systems share a preoccupation with the nurturing of individual scientific talent, and as a result are more or less on a par with regard to the quality of their scientific output.*

The gathering of talent brings not merely rewards proportionate to the amount of talent but also rewards that are, at least in the early stages of a new field, nonlinear and disproportionate. In other words, the contributions of n really good persons working in related areas of the same field are likely to be larger (or better) than n times the contribution of any one of them alone in the field. This is true of a group as well as of individuals who do not work in physical proximity to one another.

* It follows that any relaxing of social, economic, or other barriers which prevent talent from finding its proper scope is to be encouraged. Physicists would do well to ponder whether the amazingly low number of women in physics (2½ percent) in the United States is not indicative of such barriers, particularly in view of the larger fraction typical of other technically advanced countries. Disturbing and not unexpected difficulties of another kind are discussed in Russell Middleton, "Racial Problems and the Recruitment of Academic Staff at Southern Colleges and Universities," *American Sociological Review*, 1961, *26*: 960. On the other hand, the obvious distribution of the authors' names in Figure 1 sets a certain norm for any field. The standard of social mobility implied by this case has very little to do with respect to science *per se*, but everything with respect to the seriousness of one's interest in the excellence of scholarship.

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With respect to the former, the particular way group work or cooperative research functions was long ago discovered and exploited by industrial laboratories and by medical researchers. Although some group research existed as far back as the seventeenth century, and beginnings of cooperative research even on something like the present scale of groups had been made, notably in the Cavendish Laboratory and E. O. Lawrence's laboratory at Berkeley, physicists did not really understand its full merits until the creation of the World War II laboratories (the Manhattan District, the Massachusetts Institute of Technology Radiation Laboratory, the Harvard Radar Countermeasures Laboratory, and others). Not only did they learn what it meant to do science when the rest of society is really backing science (a lesson not forgotten); more particularly, they discovered how to work together in groups, despite the fact that a member may be neither particularly inclined to gregariousness nor even informed in detail on the subject of his neighbor's specialization.

What took place here was analogous to impedance matching, the method by which an electronics engineer mediates between the different components of a larger system. That is, special coupling elements are introduced between any two separately designed components, and these allow current impulses or other message units to pass smoothly from one to the other. Similarly, in these quickly assembled groups of physicists, chemists, mathematicians, and engineers, it was found that the individual members could learn enough of some one field to provide impedance matching to one or a few other members of the group. They could thus communicate and cooperate with one another somewhat on the model of a string of different circuit elements connected in one plane, each element being well enough matched to its immediate neighbors to permit the system to act harmoniously. While an applied organic chemist, say, and a pure mathematician, by themselves, may not understand each other or find anything of common interest, the addition of several physicists and engineers to this group increases the effectiveness of both chemist and mathematician, *if* each scientist is sufficiently interested in learning something new.

That this system worked was a real discovery, for the individual recruits had come largely without any experience in group research. And while during the war the system of cooperative research was tried out successfully on applied, or "mission-directed,"[20] research on a large scale, it was continued after the war in many places in

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basic science, at first on a much smaller scale—and it was still found to work to great advantage.

Another and even more important effect of group work on the growth of a field exists among eager groups in the same field who are, however, not side by side but located at some distance from one another. One research team will be busy elaborating and implementing an idea—usually that of one member of the group, as was the case with each of the early accelerators—and then will work to exploit it fully. This is likely to take from two to five years. In the meantime, another group can look, so to speak, over the heads of the first, who are bent to their task, and see beyond them an opportunity for its own activity. Building on what is already known from the yet incompletely exploited work of the first group, the second hurdles the first and establishes itself in new territory. Progress in physics is made not only by marching, but even better by leapfrogging.

To be sure, this method of locomotion is the way that interplay in the work of individuals can help to assure rapid advances; and the most valuable scientists are precisely those who can leapfrog by themselves farther than groups can. Yet, in sum, the presence of groups assures that their imagination and combined follow-up potential will allow frequent long jumps ahead into qualitatively different territory.

We can turn for a specific illustration to accelerators, not because they are glamorous or unique, but because quantitative data are easy to find there. Ernest Rutherford suggested in 1927 that the nucleus should be explored by bombarding it with artificially accelerated particles, because the natural projectiles available from radioactive sources are neither continuously controllable in speed nor of high enough energy. This gave rise at the Cavendish Laboratory in the early 1930's to the design and construction by J. D. Cockcroft and E. T. S. Walton of an accelerator for protons. Its first successful operation is represented by a black circle near the left edge of Figure 2.[21] Improvements since then have increased the top operating energy, e.g., in the proton linac, from the original one million electron volts (1 Mev) to about 60 Mev (note the nonlinear, i.e., logarithmic scale on the ordinate). But in the meantime, a profusion of new machines of quite different types have made their appearance, one after another. The cyclotron of E. O. Lawrence and M. S. Livingston (1932) was a radically different machine, and it immediately rose to higher operating energies; but this curve later

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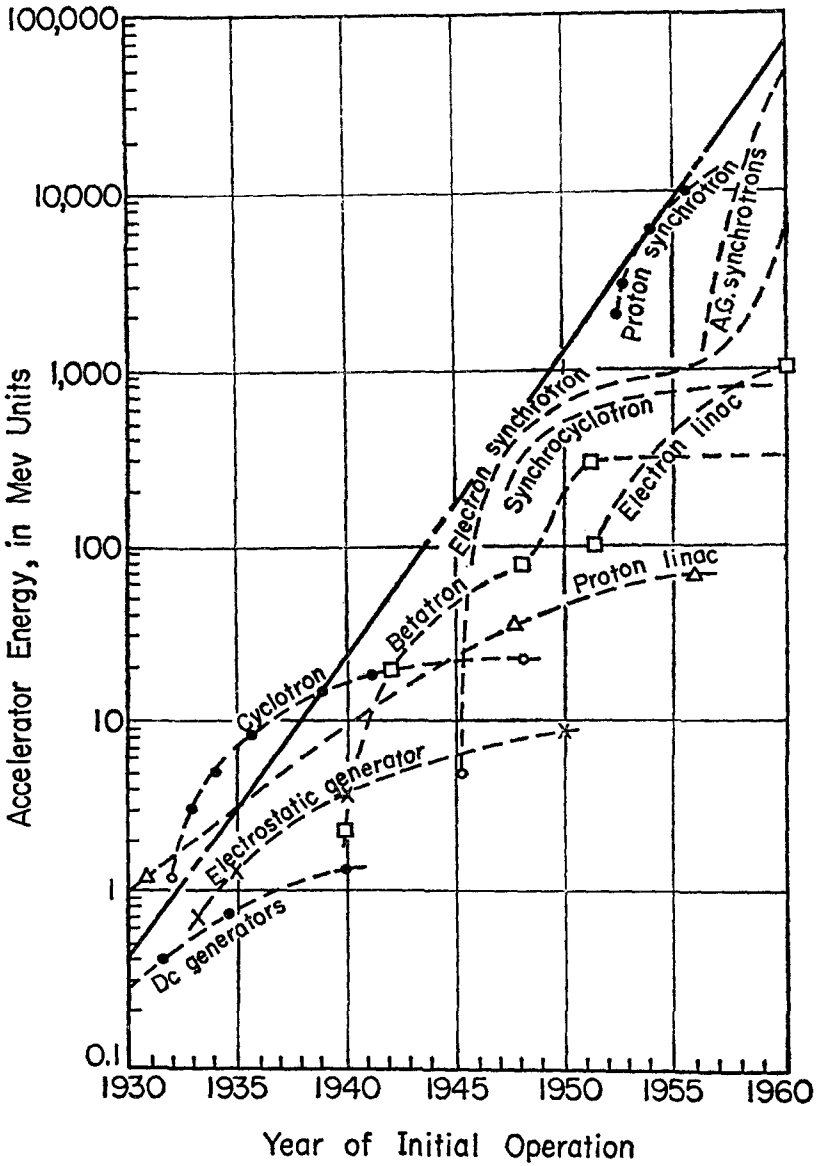

Figure 2. The rate of increase of operating energy in particle accelerators. (Courtesy of M. S. Livingston.)

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flattened out (owing to the impossibility of a fixed-frequency resonance accelerator of this type to impart effectively more energy to particles when these have already achieved a significant relativistic mass increase).

The electrostatic generator, initiated by Van de Graaff at the Massachusetts Institute of Technology, entered the situation at about this time, with less energy but with useful advantages in other ways. It differed from its two main predecessors qualitatively (i.e., in the fundamental method of achieving the accelerating voltage), as indeed these differed from each other. In 1940 the betatron—again a fundamentally different machine—started with a design by D. W. Kerst at the University of Illinois, and then entered regions of higher and higher energies, where new phenomena could be expected to occur. New machines are continuing to come from different groups and widely dispersed laboratories; the leapfrogging process is clearly at work and opens up more and more spectacular fields for basic research.

One cannot help noticing an unexpected but crucial result in Figure 2. The heavy straight line (which would be an exponentially upturned curve if it were on an ordinary plot instead of on the semilog coordinates) of course indicates roughly the approximate maximum accelerator energy available to physicists in any year. This line shows that the top energy increased on the average by a factor of about ten every five years—for example, from about 500 Mev in 1948 to about 5,000 Mev (i.e., 5 Bev) in 1953. At this rate, the 33,000 Mev Alternating-Gradient Synchrotron at the Brookhaven National Laboratory, first operated on 29 July 1960, was ready none too soon. The possibility of going into the next higher range by means of two large accelerators whose particle beams will collide with one another is now being discussed.

This ten-fold (i.e., order-of-magnitude) increase in energy every five years entails a corresponding opening up of interesting results and new fields of work, each of which will keep research projects going for a long time. The multiplication of fields and results constitutes a graphic example of what is meant by an increase in scientific activity in one area. This, too, is a particular and peculiar pattern of physical science—although, of course, the time for a doubling of range or scale is not so short in most other areas of physics.* The driving force here is in large part a simple and

* Exponential increases in range or accuracy have long been a part of scientific advance, but the doubling rate was smaller. Thus between 1600 and 1930,

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general psychological one: Particularly when the more onerous material constraints on the realization of an ingenious new idea are removed, the really original person is not likely to be interested in spending his creative energy on something that produces much less than a three-fold, five-fold, or preferably an order-of-magnitude change. This has always been true, even when the financial considerations prohibit the realization of the idea, or when costs are inherently no great factor. A five- to ten-fold increase in accuracy of measurement or of prediction; an extension of the accessible pressure range from 2,000 atmospheres to 10,000, then to 50,000, then to above 200,000; an eight-fold increase in the volume of space seen by a new telescope—these are obviously interesting and worthy goals. On the other hand, to increase the precision or range in an area by, say, 30 percent is good, but is not likely to generate special enthusiasm in an individual or a particular group.

The natural pace, therefore, is that of doubling (or more), and of doing so rapidly. As in developments in the military missile field, the urge is strong to design an accelerator which will be beyond the one now being readied for its first tests. Leapfrogging has become somersaulting. But not all physics is accelerator-bound, just as not all science is physics, and so a balance is preserved in the large.

These considerations apply directly only to experimental physics, and even then only to those research projects that go after an extension of knowledge that can be associated with an increase of some numerical index such as range or accuracy. It therefore does not refer to such experimentation as the investigation of G. P. Thomson, which was intended to confirm whether or not an electron beam exhibits wave properties, and it also does not refer to much theoretical work. Models to deal with these cases are nevertheless possible—for example, by using as a quantifier the criterion of the inclusion in one framework of previously unrelated elements, and the production of new, unrelatable entities—and such models produce the same general conclusions concerning the increase of pace.

Diffusion Speed and Critical Rates

Nothing is more striking in a high-metabolism field such as

approximately, the accuracies of measuring time and astronomical angular distance each increased fairly consistently at an average doubling time of about 20 years. For data, see H. T. Pledge, *Science since 1500* (New York: Harper & Brothers, 1949), pp. 70, 291.

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physics or experimental biology than the usefulness of the present. For example, M. M. Kessler[22] has found that 82 percent of the references cited in research papers published in the *Physical Review* during the last few years are references to other recent articles in scientific journals. Half of these articles cited are less than three years old! Reference to the more distant past decreases quite sharply; only 20 percent of all references are seven years old or more.

After journal citations, the next most frequent references (about 8 percent) are to private communications, unpublished or to be published; if the latter, they are usually in preprint form, the old standard method of communicating in a specialty field, a method which has now grown markedly. References in *Physical Review* articles to books turn out to rank only third, or 6½ percent (the remaining 3½ percent of references being to industrial reports, theses, etc.). Even these books seem increasingly often to be edited volumes of various articles. The net effect, then, is that of the diffusion and use of information at high speed.*

There are other ways in which scientific information diffuses and is used. Nothing, surely, is a more viscous medium for diffusion than the educational system of college and high school. How do the advances of science fare there? We know that the situation is not yet satisfactory, and we can understand the difficulty that must arise whenever the diffusion time is radically different from the natural pace of research. An example is the treatment of special relativity theory in a long-established senior-level physics text, such as F. K. Richtmyer's *Introduction to Modern Physics*. In the first edition (1928) the theory of relativity occupied about a page. Six years later came the second edition, with twelve pages on this topic, gathered in an appendix. The third edition, eight years later, had a separate, regular, thirty-page chapter in the text. And in subsequent editions of this outstanding text the material has properly spread throughout the book so that it is meaningless to make an estimate of the actual space given it. But then, little had been added to special relativity theory as a separate research topic since long before 1928.

* Not surprisingly, the speed of advance implies a degree of waste, and a number of simultaneous efforts along virtually identical lines. I have discussed elsewhere other reasons for the necessity of some wastefulness and for synchronicity in scientific work; for example, in the *American Scientist*, 1953, *41*: 89-99, and the *American Journal of Physics*, 1961, *29*: 805-810. Nothing here should be taken as a defense of much that is merely expensive large-scale gadgetry, but which passes for science under such labels as "Space."

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Alternatively, by making a cut through the educational system another way, one can follow the progress of ideas as they move from the research desk down to the schoolroom. The emanation electroscope was a device invented at the turn of the century to measure the rate at which a gas such as thorium emanation loses its radioactivity. For a number of years it seems to have been used only in the research laboratory. It came into use in instructing graduate students in the mid-1930's, and in college courses by 1949. For the last few years a cheap commercial model has existed and is beginning to be introduced into high-school courses. In a sense, this is a victory for good practice; but it also summarizes the sad state of scientific education to note that in the research laboratory itself the emanation electroscope has long since been moved from the desk to the attic. The high rate of turn-over of ideas in science presents almost insoluble problems for a conventional educational system in which information about the events at the top are propagated slowly and without a short-circuiting of any of the intermediate elements below.

In order to have a better model of the process by which knowledge in a research field advances, we must think about the rate of diffusion along yet another dimension. In all fields of scholarship, the inputs for a lively research topic are not restricted to a narrow set of specialties, but can come from the most varied directions. In physical science it is easy to document this process of the diffusion of knowledge from many sides, over a period of time, into one research area—on the part of individuals, and quite independently of the effectiveness of groups dealt with earlier. Figure 3 is a schematic design intended to give, in rough approximation, both a feeling for what may be meant by the "growth of a field" and an overview of the cumulative effects of contributions from various scientific specialties.[23]

The field chosen is that of shock waves. It is a "classical" research subject that originated in 1848 when the British mathematician and physicist G. G. Stokes and the astronomer and mathematician J. Challis communicated their struggles with solutions of the equation of motion in a gas as developed by Poisson in 1808. Stokes was led to propose, on theoretical grounds, that a steep gradient in velocity and density should exist in the gas if a large disturbance were propagated in it. Both their contributions are represented by the two arrows at the far left, the directions of the arrows indicating the specialty fields involved.

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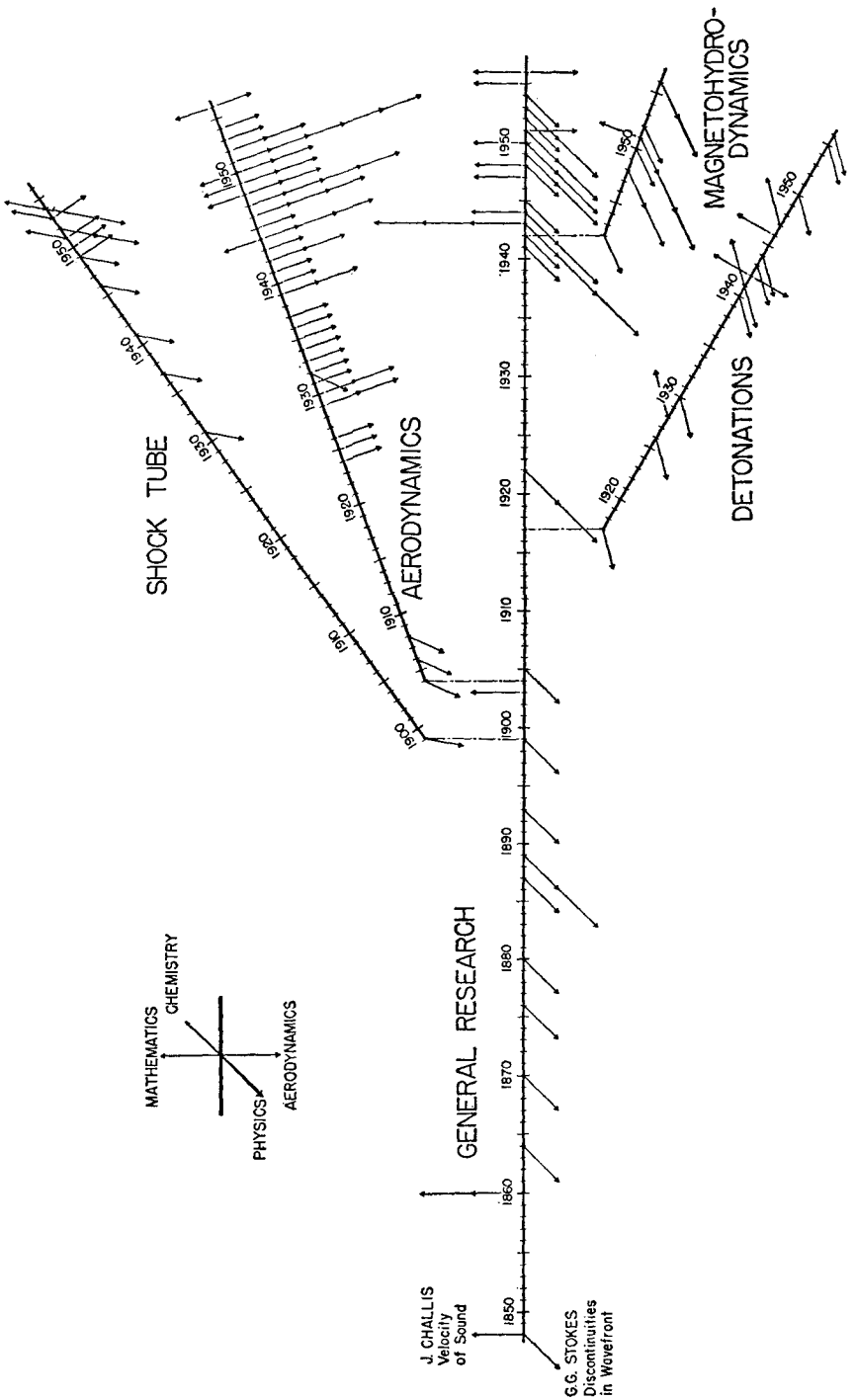

Figure 3. A representation of the development of basic research and of some applications. Each arrow represents a major contribution. Its direction indicates the specialty field involved (see coordinate system at the top left); for example, an arrow rising perpendicularly from the time axis represents mathematics.

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The successive events are similarly indicated. For example, further basic work in the mathematics of wave propagation by Riemann and by Earnshaw follows in 1860, and other arrows placed on the "General Research" line refer to contributions in mathematics by men such as Hadamard (1903), Chandrasekhar (1943), and Kantrowitz (1951), or in physics by Mach (1876, 1887, 1889), Bethe (1942), von Neumann (1943), and Truesdell (1951). New specialty fields branch off as shown from time to time, some having pronounced technological orientation; but it is illustrative of the difficulties of clear separation that a branch such as magnetohydrodynamics (where the initial arrow indicates the work by Alfven in 1942) now plays a fundamental part in both basic and applied fusion research. The increasing activity is evident throughout. As these lines go forward, one may well expect further branchings at the growing edge from any of the five present lines, and fundamental contributions along any of the four dimensions. It is becoming more and more evident that departmental barriers are going to be difficult to defend.

Another illustrative interpretation of cumulative growth is obtained by following, on a shorter time scale than Figure 3, the effect and interrelationship of a few particularly creative and stimulating persons within a field. Figure 4 represents the results of a recent study,[23] tracing in general terms the rise of the fields of molecular beams, magnetic resonance, and related work in pure physics. In particular, it is focused on one part of the extensive achievement of I. I. Rabi, both in developing the original molecular beam techniques, and in selecting and stimulating a group of productive associates or students (whose names are underlined on the chart in Figure 4).*

This description is analogous to making a large magnification of a small part of the previous figure to determine its "fine structure." After working with Otto Stern in Hamburg, Rabi in 1929 effected a branching-off from previous lines of research (analagous therefore to Alfven's arrow for 1942 at the head of the magnetohydrodynamics line in Figure 3, or the arrow on the aerodynamics line for Prandtl in 1904). It can be seen that soon after, both in independent laboratories as well as in those of Rabi and his associates, the applicability of the early techniques, and the originating of new questions

* It should be understood that this chart does not pretend to an exhaustive description of all work in this field, and in particular does not indicate any work by these persons in other fields.

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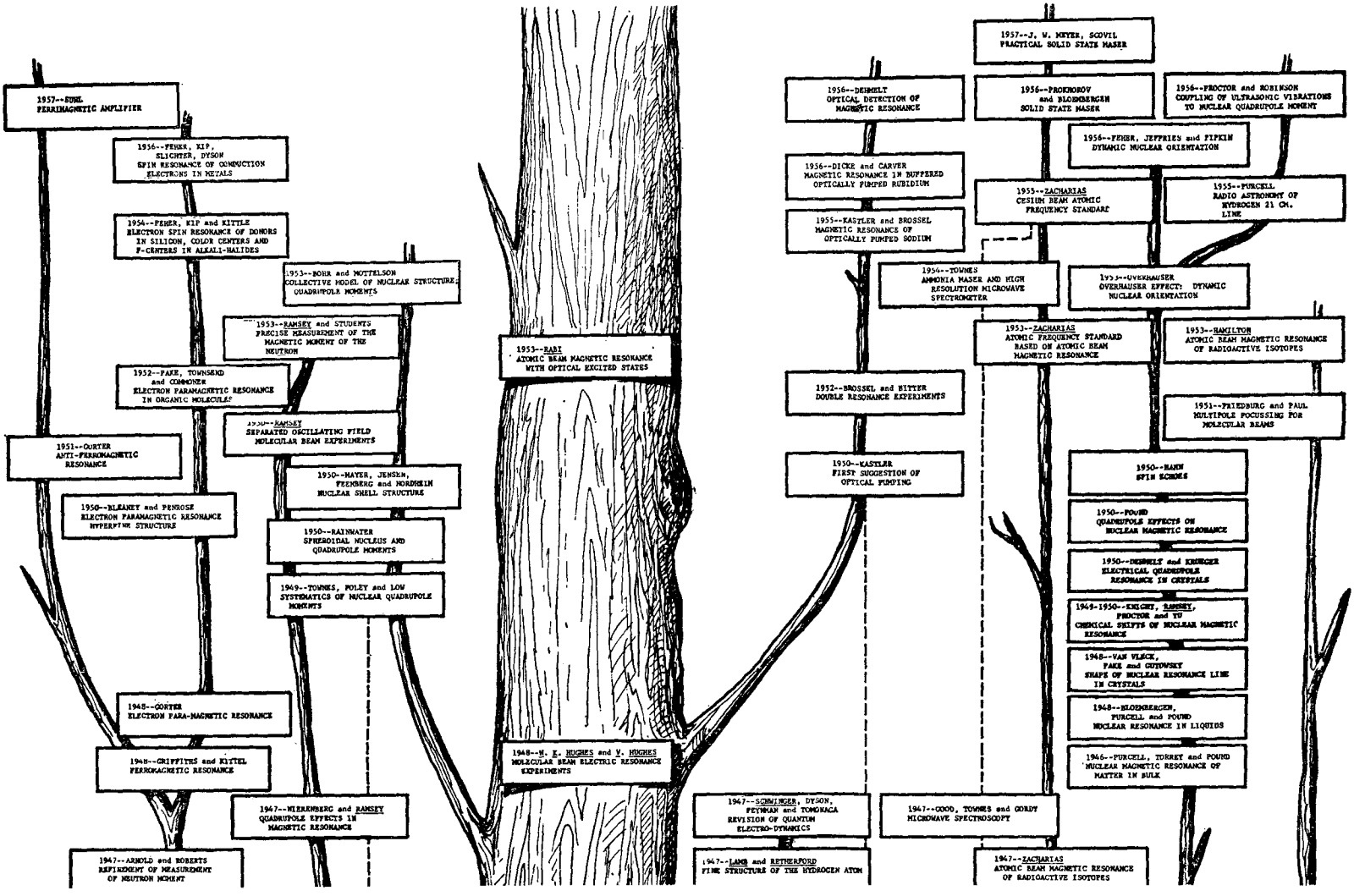
1957--SUHL
FERRIMAGNETIC AMPLIFIER
1956--FEHER, KIP, SLICHTER, DYSON
SPIN RESONANCE OF CONDUCTION ELECTRONS IN METALS
1954--FEHER, KIP and KITTEL
ELECTRON SPIN RESONANCE OF DONORS IN SILICON, COLOR CENTERS AND F-CENTERS IN ALKALI-HALIDES
1953--BOHR and MOTTELSON
COLLECTIVE MODEL OF NUCLEAR STRUCTURE; QUADRUPOLE MOMENTS
1953--RAMSEY and STUDENTS
PRECISE MEASUREMENT OF THE MAGNETIC MOMENT OF THE NEUTRON
1952--FAKE, TOWNSEND and COMMONER
ELECTRON PARAMAGNETIC RESONANCE IN ORGANIC MOLECULES
1950--RAMSEY
SEPARATED OSCILLATING FIELD MOLECULAR BEAM EXPERIMENTS
1951--CORTER
ANTI-FERROMAGNETIC RESONANCE
1950--BLEANEY and PENROSE
ELECTRON PARAMAGNETIC RESONANCE HYPERFINE STRUCTURE
1950--MAYER, JENSEN, FEENBERG and NORDHEIM
NUCLEAR SHELL STRUCTURE
1950--RAINWATER
SPHEROIDAL NUCLEUS AND QUADRUPOLE MOMENTS
1949--TOWNES, FOLEY and LOW
SYSTEMATICS OF NUCLEAR QUADRUPOLE MOMENTS
1948--CORTER
ELECTRON PARA-MAGNETIC RESONANCE
1948--GRIFFITHS and KITTEL
FERROMAGNETIC RESONANCE
1947--WEXENBERG and RAMSEY
QUADRUPOLE EFFECTS IN MAGNETIC RESONANCE
1947--ARNOLD and ROBERTS
REFINEMENT OF MEASUREMENT OF NEUTRON MOMENT
1953--RABI
ATOMIC BEAM MAGNETIC RESONANCE WITH OPTICAL EXCITED STATES
1948--H. K. HUGHES and V. HUGHES
MOLECULAR BEAM ELECTRIC RESONANCE EXPERIMENTS
1957--J. W. MEYER, SCOVIL
PRACTICAL SOLID STATE MASER
1956--DEHMELT
OPTICAL DETECTION OF MAGNETIC RESONANCE
1956--PROKHOROV and BLOEMBERGEN
SOLID STATE MASER
1956--PROCTOR and ROBINSON
COUPLING OF ULTRASONIC VIBRATIONS TO NUCLEAR QUADRUPOLE MOMENT
1956--FEHER, JEFFRIES and FIPKIN
DYNAMIC NUCLEAR ORIENTATION
1956--DICKE and CARVER
MAGNETIC RESONANCE IN BUFFERED OPTICALLY PUMPED RUBIDIUM
1955--ZACHARIAS
CESIUM BEAM ATOMIC FREQUENCY STANDARD
1955--PURCELL
RADIO ASTRONOMY OF HYDROGEN 21 CM. LINE
1955--KASTLER and BROSSEL
MAGNETIC RESONANCE OF OPTICALLY PUMPED SODIUM
1954--TOWNES
AMMONIA MASER AND HIGH RESOLUTION MICROWAVE SPECTROMETER
1953--OVERHAUSER
OVERHAUSER EFFECT: DYNAMIC NUCLEAR ORIENTATION
1953--ZACHARIAS
ATOMIC FREQUENCY STANDARD BASED ON ATOMIC BEAM MAGNETIC RESONANCE
1953--HAMILTON
ATOMIC BEAM MAGNETIC RESONANCE OF RADIOACTIVE ISOTOPES
1952--BROSSEL and BITTER
DOUBLE RESONANCE EXPERIMENTS
1951--FRIEDBURG and PAUL
MULTIPOLE FOCUSING FOR MOLECULAR BEAMS
1950--KASTLER
FIRST SUGGESTION OF OPTICAL PUMPING
1950--HAHN
SPIN ECHOES
1950--POUND
QUADRUPOLE EFFECTS ON NUCLEAR MAGNETIC RESONANCE
1950--DEHMELT and KRUGER
ELECTRICAL QUADRUPOLE RESONANCE IN CRYSTALS
1949-1950--KNIGHT, RAMSEY, PROCTOR and YU
CHEMICAL SHIFTS OF NUCLEAR MAGNETIC RESONANCE
1948--VAN VLECK, FAKE and GUTOWSKY
SHAPE OF NUCLEAR RESONANCE LINE IN CRYSTALS
1948--BLOEMBERGEN, PURCELL and POUND
NUCLEAR RESONANCE IN LIQUIDS
1946--PURCELL, TORREY and POUND
NUCLEAR MAGNETIC RESONANCE OF MATTER IN BULK
1947--SCHWINGER, DYSON, FEYNMAN and TOMONAGA
REVISION OF QUANTUM ELECTRO-DYNAMICS
1947--LAMB and RETHERFORD
FINE STRUCTURE OF THE HYDROGEN ATOM
1947--GOOD, TOWNES and GORDY
MICROWAVE SPECTROSCOPY
1947--ZACHARIAS
ATOMIC BEAM MAGNETIC RESONANCE OF RADIOACTIVE ISOTOPES

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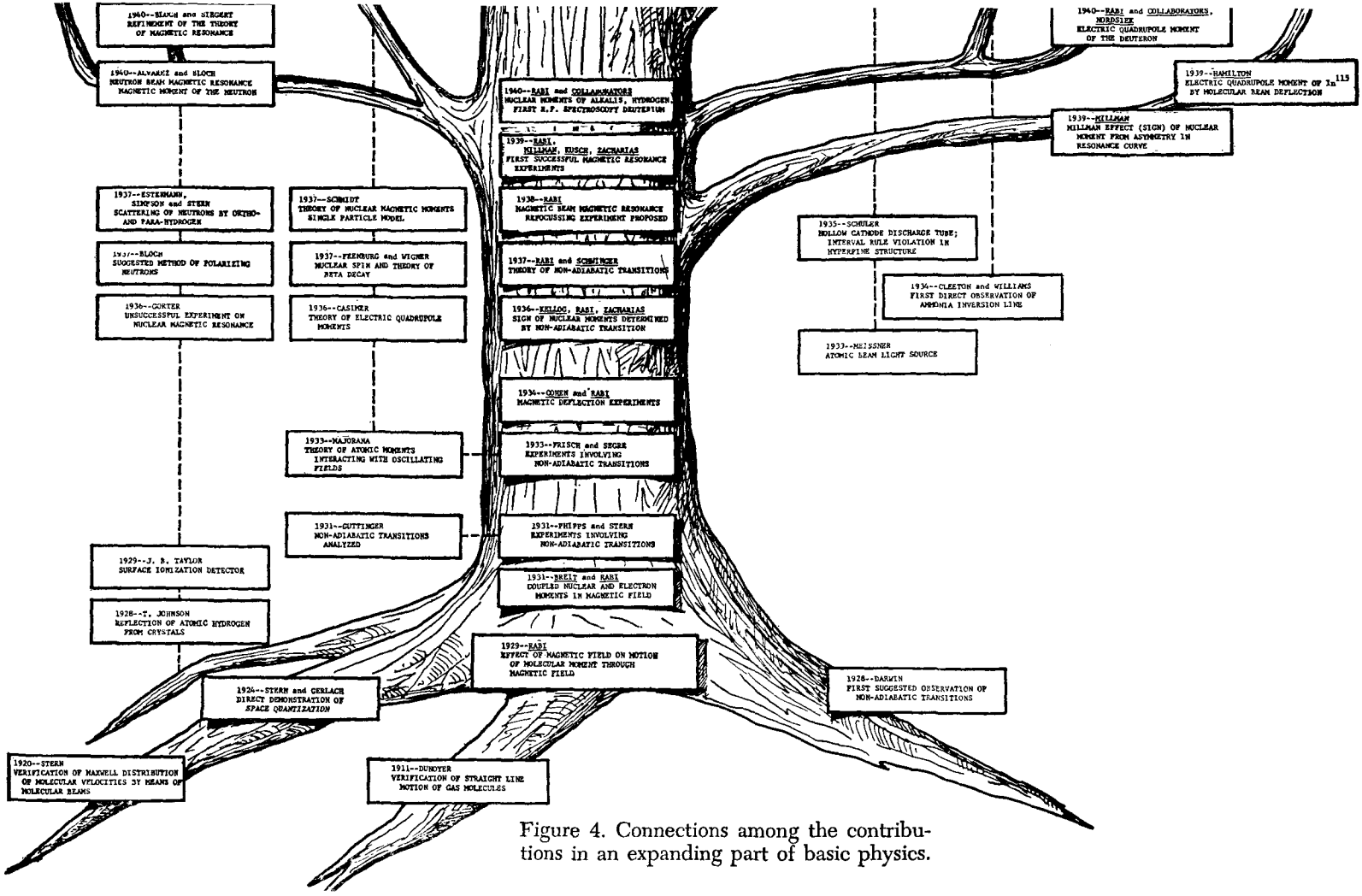

Figure 4. Connections among the contributions in an expanding part of basic physics.

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now suggesting themselves in neighboring parts of the same fields, provoked a rapid branching into several new directions. The excitement of this field as a whole and its fruitfulness are attested by the large rate of inflow of new persons, including many outstanding experimental and theoretical physicists.

The course of the future is clearly going to be a continuing multiplication on the same general pattern. And although the growth is more eye-catching at the end portion of each branch, there is still a fruitful harvest in many of the lower boxes in Figure 4. Thus, molecular beams themselves remain important in current research. Finally, the connections with the technological exploitations of these advances have not been represented; but one should be aware that such connections almost invariably exist, and in this case they could be shown at several points (for example, maser, atomic clock).

A Simple Model for the Growth of Research in Science

We may now correlate the descriptive details in a simple qualitative model of the growth process of scientific research. It is too ambitious to expect such a model to tell us "how science works," but it should help us to understand its more bewildering and spectacular aspects.

A hypothetical construction should start with a "zeroeth-order" approximation; that is, we know it to be inadequate from the beginning, but we also know how to improve it to attain a first-order approximation and, if possible, higher-order approximations later. Such a start is provided by Newton's analogy of having been on the shore of the known, "while the great ocean of truth lay all undiscovered before me." Scientists do indeed seem generally to think about basic research in terms of some such picture. They often have described it as if it were a voyage of discovery launched on uncharted waters in the hope of reaching a new shore, or at least an island. To be sure, neither research nor a sea voyage is undertaken without some theory that serves as a rough chart. Yet such vague terms are used, even when the promise of end results would strengthen the cause of the hopeful explorer. Thus during a recent Congressional inquiry to ascertain the large financial needs for future accelerator constructions, the scientists—quite properly—gave Congress no more definite commitment of returns on the considerable investment it was asked to undertake than this:*

* "A Ten-year Preview of High Energy Physics in the United States.

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It is, therefore, likely that the next decade will see the discovery of unexpected phenomena as well as the development of hitherto unknown techniques of particle detection and identification, and new means of particle acceleration and containment. Since it is impossible to predict the nature of these developments, it is very difficult to take their effect into account in any ten-year cost preview.

Taking the analogy of the voyage of exploration as sufficiently suggestive for the moment, we see that on the average a single searcher will expect the number of new islands he discovers to increase with time, perhaps more or less linearly. The same will be true if his is not the only ship that has started out, and if we assume the expeditions to be still few and not yet in contact with one another so as to affect the individual search patterns.

Hence the number of unknown islands yet to be found in a finite ocean (that is, the number of interesting ideas—not "the facts"—supposed to be still undiscovered in this pool) will be expected to drop off in time, somewhat as line I in Figure 5(a) does. In devel-

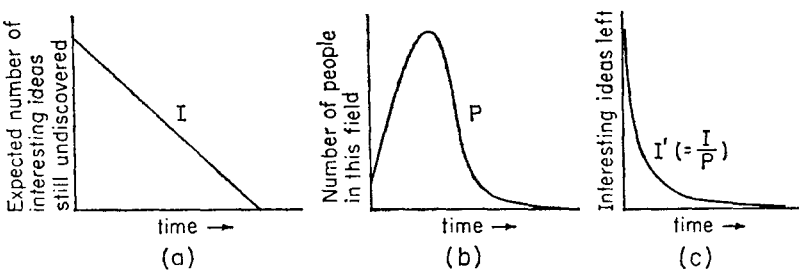

Figure 5. Zeroeth-order approximation for a model of research in a specified area.

oping a model for discovery, we shall now build a series of simple graphs on Figure 5(a) to summarize in an easily perceived form some qualitative trends.

But if Figure 5(a) itself were a proper model for discovery, science, like geographical exploration or gold-mining, would sooner or later be self-terminating. In fact, the end should come sooner rather than later, because the news of discoveries in a fruitful ocean spreads interest in them. New explorers will rush in, as shown by the

Detailed Backup for Report of Ad Hoc Panel of the President's Science Advisory Committee and the General Advisory Committee to the A. E. C., December 12, 1960," in *Background Information on the High Energy Physics Program, op. cit.*, p. 24 (see p. 369 above).

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early part of curve P in Figure 5(b). This influx by itself will assure that the quantity of ignorance remaining decreases with time in a manner shown not by curve I but by curve I′ in Figure 5(c); that is, it will drop more nearly exponentially than linearly. If one also takes into account the fact that communication among the searchers shown on curve P improves the effectiveness of each one's search (a main function of communication, after all), then the middle portion of curve I′ should really drop off even more steeply, causing I′ to have the shape of an inverted sigma; and this is precisely what the data presented in Figure 2 indicate. In either case, however, the specified field will in time become less attractive, and the number of investigators will be decreasing somewhat as shown. Curve P thus indicates directly the size of the profession at any time, and indirectly—by the steepness of the slope of P—the intensity of interest or attractiveness of the field with respect to net recruitment (the inflow minus the outflow of people).

We shall soon have to add some mechanism to explain why science as a whole increases in interest and scope instead of deteriorating, as in Figure 5. Nevertheless, we already recognize that for some specific and limited fields of science this model is useful. Thus in 1820 Oersted's discovery of the magnetic field around wires that carry direct current, and the theoretical treatments of the effect by Biot, Savart, and Ampère in the same year, sparked a rapidly rising number of investigations of that effect; but it was not long before interest decreased, and by the time of Maxwell's treatise (1873) no further fundamental contributions from this direction were being obtained or even sought.

In fact, the same statement now applies (even in a good program) to virtually every topic presented in depth to physics students throughout their undergraduate training, and to a number of their typical graduate courses—except for students' own thesis fields. So, while Figure 5 may also be applicable to other areas of scholarship, the impressively different feature in physical science is that the time span for curve I′ has become quite short when compared with the time span of an active researcher's professional life, and frequently even when compared with the new recruits' period of training.

Figure 6 shows again in curve I′ the decrease of ignorance, together with a time scale (T, 2T, 3T, etc.) along the abscissa, drawn in such a way that the amount I′ has dropped roughly to half the initial value when period T has elapsed, to one-quarter

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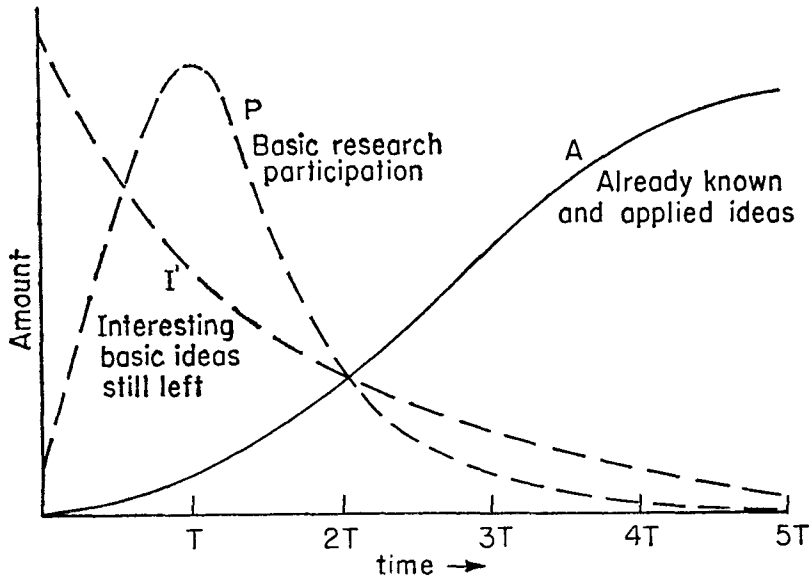

Figure 6. Inverse relationship between the accumulation of application and the interest in a basic-research field.

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after total time 2T, to one-eighth after 3T, etc. T is thus the "half life" of the suspected pool of interesting basic ideas. The statements of the last paragraph imply that T is now short, perhaps between five and fifteen years for a specific, lively field on the frontiers of physical science.* This is also in accord with the data cited earlier, which showed that in reports of new research the references to published work fall overwhelmingly within the most recent years.

While it is not intended here to give an accurate idea of the absolute scales, the relative positions, or the detailed shape of the curves, P has been placed so as to indicate that the number of active researchers will reach a maximum when a large part of the presumed total of interesting ideas has already been discovered. This suspicion and the sense of dwindling time also contribute to the evident pressure and the fast pace. It appears to me that a critical slope for I′ exists. When the rate of decrease indicated by I′ for the specific research field is not so large (that is, when T is of the order of the productive life span of individuals, or longer),

* Needless to say, one might cite a number of interesting research fields in physics in which the time scale is longer.

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the profession organizes its work, its training methods, and its recruitment quite differently than if the value for T is only a few years. There are recent examples, as the case of oceanography, of a science passing from the first phase into the second, taking on many of the sociological characteristics of physics as a profession.

By means of Figure 6 we can briefly consider the application of new findings in basic research, as indicated in curve A. Such applications include use in other fields (for example, radioisotopes in medicine), and use for applied research and development. Curve A is meant particularly for the last of these, for example in the development of an industrial product. Clearly, a curve P′ that would be similar to P could be drawn to show how the number of people engaged in applied research is likely to grow and ultimately to diminish, for it is their work which A traces out.

Such a curve P′ would have the same general shape as P, but it would be displaced to the right of curve P. For it is clear that the longer one waits before beginning to apply fundamental ideas, the more nearly one's work will seem to be based on complete knowledge. Today, however, curve A does not wait to rise until I′ has reached very small values. We can readily understand this in terms of three factors: the competitive pressures within an industry, the natural curiosity of talented people, and the needs of basic research itself—which, in experimental physics at least, is now closely linked with the availability of engineering developments of basic discoveries. A curve P′ for applied research participation will therefore overlap curve P for basic-research participation, and indeed these two populations will often draw on the same sources. For example, Kessler[22] reminds us that articles in the *Proceedings of the Institute of Radio Engineers* refer with considerable consistency to the publication of basic research in physics; in the case of a relatively new applied field, such as transistors, such references to articles in the *Physical Review* occur not much less frequently than citations to *Physical Review* articles in basic-research journals. In the past much blood has been shed over distinctions between pure and applied research. It may be fruitful to assume that a critical difference lies in the relative positions on the time axis of curve P showing the basic-research population and a corresponding curve P′ that could be drawn for the applied research population. The fruitful interaction of basic and applied science will be indicated by the overlap of these two populations, in time as well as in the sources from which they draw their material.

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A First-order Approximation

We are now ready to attempt a first-order approximation to improve our model for the progress of scientific research. For this purpose we examine Figure 7(a), where curve D is simply the mirror

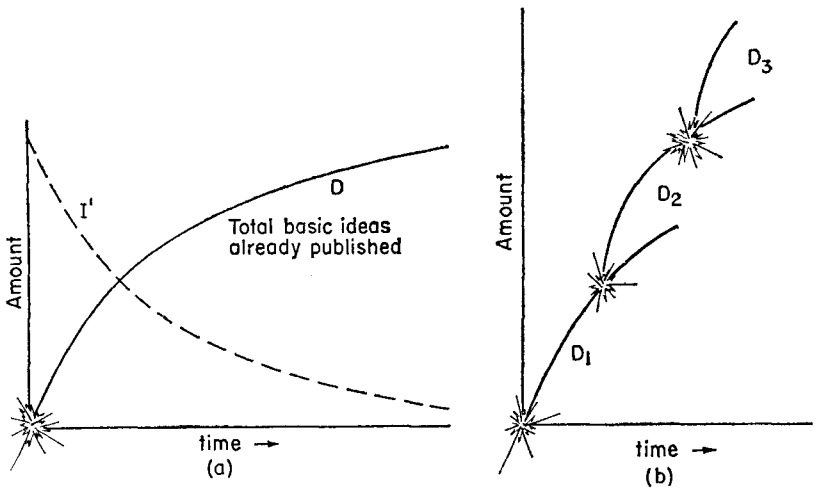

Figure 7. The escalation of discovery lines.

image of I′, plotted in the same plane. That is, whereas I′ presented the decrease of ignorance, D presents the increase of total basic "discoveries" made in the finite pool of interesting ideas. The beginning of curve D indicates necessarily the occasion that launched the expeditions in this field, say the discovery in 1934 of artificial radioactivity by the Joliot-Curies while they were studying the effect of alpha particles from polonium on the nuclei of light elements. Up to this point their research had followed a fruitful line, originating in Rutherford's observation in 1919 of the transmutation of nitrogen nuclei during alpha-particle bombardment.

The new Joliot-Curie observation, however, inaugurated a brilliant new branch of discovery. We suddenly see that the previous model (Figure 5) was fatally incomplete because it postulated an *exhaustible* fund of ideas, a limited ocean with a definite number of islands. On further exploration, we now note that an island may turn out to be a peninsula connected to a larger land mass. Thus in 1895 Röntgen seemed to have exhausted all the major aspects of X-rays, but in 1912 the discovery of X-ray diffraction in crystals

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by von Laue, Friedrich, and Knipping transformed two separate fields, those of X-rays and of crystallography. Mosely in 1913 made another qualitative change by showing where to look for the explanation of X-ray spectra in terms of atomic structure, and so forth. Similarly, the Joliot-Curie findings gave rise to work that had one branching point with Fermi, another with Hahn and Strassmann. Each major line of research given by line D in Figure 7(a) is really a part of a series D_1, D_2, D_3, etc., as in Figure 7(b). Thus the growth of scientific research proceeds by the *escalation* of knowledge—or perhaps rather of new areas of ignorance—instead of by mere accumulation.

By means of this mechanism, we can understand at the same time the pace, the proliferation, and the processes of diffusion and branching shown in Figures 3 and 4. When an important insight (including a "chance" discovery) causes a new branch line D_2 to rise, fruitful research usually continues on the older line D_1. But many of the most original people will transfer to line D_2, and there put to work whatever is applicable from their experience along D_1. (Perhaps now the most important thing to know is when to drop D_1 and go to D_2.) If the early part of D_2 rises steeply—because there is now a new area of ignorance that can be filled in at a rapid initial rate—then D_2 will appear as an exciting field, and will be very attractive to researchers. Many will switch to D_2; but the largest source of ready manpower is the new recruits to the field. Hence the lively sciences have a constant need to "grow," or at least to enlarge the profession. This may well run eventually into difficulties as the limitation of available talent sets an upper boundary to possible growth.[24]

The newest recruits, therefore, are likely to be serving their apprenticeship at the newest and most rapidly growing edges. This is an excellent experience for them. But rapidity of growth depends on the inflow of research talent, and at the same time it is also *defined* by the output achieved. Thus there appears a danger of self-amplifying fashions: from a long-range point of view, too many people may be crowding into some fields and leaving others undermanned. One partial remedy has been for the less fashionable fields to set up their own professional specialty organizations and their own training and recruitment programs—a process which, once initiated, further polarizes the narrowing subsections within science as a whole.

With the concept of escalation in mind, let us finally re-examine

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Figure 2, where we found a leapfrogging progress to ever higher accelerator energies. The two concepts are intimately related; Figure 2 indicates the application of the escalation process of Figure 7(b) to a narrow and particularly vigorous specialty, that of accelerator design.[25] The same analysis may be applied directly to other experimental fields which do not have such strong increases in the value of an easily identifiable variable. But it should again be stressed that advances in most theoretical aspects of science, and in not a few experimental ones, do resist quantification, and that then no analogue to Figure 2 can be readily drawn. Nor should this be unexpected. In the end, what any advance must be judged by is not some quantifiable improvement in a specialty, but the qualitative increase in the depth of understanding it contributes to a wide field. For this reason, our model for the growth of science must, and should, remain qualitative.

We may now summarize. We have described what is considered an adequate system designed to support the pursuit of interesting ideas that add to man's basic knowledge—a system that aids researchers to do this sooner rather than later, and with work and luck to make a large difference to the state of knowledge of their field. We have noted the availability of means, of time, of collaborators, of encouragement by one's fellow-men, and of the stimulus of new results, all of which keep morale high; the open invitation to talent, no matter what real or imagined barriers to it may exist elsewhere; the aid given from student days forward for continued education; the predominantly youthful character of the profession, with the inflow of bright young people that is steadily growing; and the sense of building on the contribution of others. This, I believe, would be a fair description of the major features of most basic-research sciences as professions in the United States today, whatever their faults may be in detail.

But none of these traits is inherently and necessarily restricted to the profession of science. (Indeed, in the past, perhaps the majority of these traits did not describe any science well.) The description in the paragraph above might well apply to most fields of scholarship, but it does so only in some cases. In this sense I regard this contemplation of the physical sciences as useful, not because their methods are to be imitated, but because they, more than many other fields, have achieved a state of operation that need have nothing to do with science as science, but only with academic science as a profession.

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The description of it given above should allow us to distinguish between what is unique to science and what is not. It is not to the point to say that historians must be mature men before they can be historians, or that the Romance languages did not help build bombs and have no need of cyclotrons, and that the Navy is not waiting for break-throughs in theology. It is also not to the point to say that science is unique in its attention to quantifiable knowledge, in its need for cumulative growth, or in its luck or its ability to survive periods of acceleration in growth. Certainly, the clamor for more money and more manpower for its own sake is always wrong, even in science, and it can be fatal outside science. Perhaps, indeed, we need no increase in the rate of scholarly production of studies in Byzantine art or even in the history of biology. *But even in science,* the quantitative aspects of "growth" are merely indices of deepening understanding. Therefore, the question now must be: Given these differences between the needs of special fields of scholarship, and given agreement with the descriptive paragraph above as a worthy goal for any field of scholarship, what can we do to achieve this aim for each of the particular fields?

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1. R. T. Birge, "Physics and Physicists of the Past Fifty Years," *Physics Today,* 1956, 9: 23.
2. Byron E. Cohn (editor), *Report of the Conference on Curricula for Undergraduate Majors in Physics* (University of Denver, August 1961), p. 12.
3. *Statistical Abstract of the United States, 1961* (82nd edn.), p. 130.
4. Birge, *op. cit.*
5. *Scientific Manpower Bulletin No. 12,* National Science Foundation 60-78, December 1960.
6. Interim Report of the American Institute of Physics Survey of Graduate Students (mimeographed). With fellowship or scholarship aid, the median time now taken for the doctoral degree in physics is 4.31 years; without such aid, 4.84 years.
7. *Ibid.*
8. *The Long Range Demand for Scientific and Technical Personnel,* National Science Foundation 61-65, 1961, pp. 42 and 45. All too often the sciences are discussed as though they were all physics. To obtain perspective, the total number of United States physicists of all kinds (under 30,000) should be measured against the total number of professional scientists and

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engineers in industry alone: without counting scientists in government or physicians who do medical research, the number is 850,000. (See *Scientific and Technical Personnel in Industry, 1960,* National Science Foundation 61-75, 1961.) If government scientists, research-minded physicians, and science teachers are added, the total is 1,400,000. (See *Investing in Scientific Progress,* National Science Foundation, 1961, p. 18.) It had been estimated that only 27,000 in this large group are basic-research scientists, and that 15,000 of the latter are particularly active—the "real" scientists, as it were. (See *Basic Research in the Navy,* vol. I, Naval Research Advisory Committee, 1959, p. 29.)

9. *Scientific Manpower Bulletin No. 14,* National Science Foundation 61-44, 1961, p. 6.

10. *Ibid.,* p. 5. Also A. E. S. Green, "Scientific Salaries," *Physics Today,* 1962, *15*: 41.

11. *The Long Range Demand for Scientific and Technical Personnel, op. cit.,* p. 43. The reasons why he will probably continue in a university are significant. The mobility of a good man within the academic system in the United States plays a major part in the decision.

12. C. B. Lindquist, "Physics Degrees during the 1950's," *Physics Today,* 1962, *15*: 20.

13. *Scientific Manpower Bulletin No. 13,* National Science Foundation 61-38, 1961, pp. 3 and 6.

14. *Bulletin of the American Physical Society,* Series II, vol. 7, 24 January 1962.

15. No fact of science has ever been as difficult to verify as the figure given out as basic-research expenditure. For example, the budget submitted by the President on 19 January 1962 contains $12.4 billion for "Research and Development" (including that for the Department of Defense, and Space Research and Technology). Of this sum $1.6 billion is said to be for "basic" research and training, including the programs of the National Institutes of Health, the National Science Foundation, and Agricultural Research, as well as large sums for the Atomic Energy Commission, Space, and unspecified items for the Department of Defense. Since in the past years the total sum spent for basic research from all sources has been about twice what the Federal government supplied, one might arrive at a total bill of from $2.5 to $3 billion for basic research in all sciences for the fiscal year 1962, or about half of one percent of the Gross National Product. However, a more likely figure for 1963, particularly if use is made of a stricter interpretation of "basic research," is half this sum (or an average of about $8 per person living in the United States) for all basic scientific research in physics, metallurgy, experimental psychology, medicine, etc.

    For comparison, note the latest data in "Funds for Basic Research," *Statistical Abstract, op. cit.,* p. 534. The total expenditures in 1959-1960 are (preliminary) $1.149 billion, and the details list $0.225 billion for basic research performed by the Federal government, $0.344 billion for that performed by industry, $0.500 billion for that performed by colleges and

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universities (including research centers they administered), and $0.080 billion for that performed by other nonprofit institutions.

16. I will refrain from elaborating on the point that the new scientist now seems to have at least as much time and energy for other socially valuable activities as previous generations did. For example, a large number of distinguished scientists participate prominently in national voluntary advisory or citizens' groups, or give thought and help to one of about ten current national elementary and high-school or college programs for improving curricula in science.

    Because in themselves they are either not new or not intrinsically unavoidable parts of the present pattern of science, I shall equally refrain from elaborating here some of the persistent and well-known complaints raised by scientists themselves: the volume of material to digest, the imbalance between different special fields, the encroachment of bureaucracy and of military technology, the need for keeping some "big science" efforts big and in the news by artificial means, the poverty of many teaching efforts. (For brilliant discussions of some of these and related points, see the essays by Merle A. Tuve in *Symposium on Basic Research,* edited by Dael Wolfle [Washington: American Association for the Advancement of Science, 1959], and by A. M. Weinberg, "Impact of Large-Scale Science on the United States," *Science,* 1961, *134*: 161.)

    I shall also neglect here the occasional pirate who is drawn to the scientific field, as in earlier times a man of talent with a like soul would have found scope for his aspirations in the service of a queen or a Boniface III. The obligations and opportunities of power and all it entails now lie on many of the most outstanding scientists. A thorough and sympathetic study of the situation is in *Conflict of Interest and Federal Service* (Cambridge: published for the Association of the Bar of the City of New York by the Harvard University Press, 1960), chapter 7.

17. *Science,* 1961, *134*: 456.

18. A. N. Nesmeyanov, "A Great Victory of Soviet Science," *Vestnik,* Akademiia Nauk SSSR, 1959, 28: no. 11, pp. 3-9.

19. *Proceedings* of the Institute of Radio Engineers, 1959, *47*: 1052.

20. This is the place to mention (without entering into it) the debate on the difficult problem of distinguishing among basic research, applied research, development, technology, quality control, and technical services. These form a continuous spectrum, and precise definitions do not survive the test of using them and talking about them. Suffice it to say that different panels of physicists and engineers working together usually manage to discriminate between these activities on the basis of brief descriptions. For a discussion, see the essay by D. Wolfle, in *Symposium on Basic Research, op. cit.,* Ref. 16.

21. From M. S. Livingston, *The Development of Particle Accelerators.* New York: Dover Publishing Company (to be published). Reproduced by permission. A similar chart is in M. S. Livingston and J. P. Blewett, *Particle Accelerators* (New York: McGraw-Hill Publishing Company, 1962), p. 6.

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22. *Proceedings of the Western Joint Computer Conference,* 1961, pp. 247-257, and private communications.

23. Based on data presented in *Basic Research in the Navy, op. cit.,* vol. 1. I thank Dr. Bruce S. Olds for arranging the release of the material for use here.

24. See Dael Wolfle, *America's Resources of Specialized Talent* (New York: Harper and Brothers, 1954), p. 192.

25. The model here proposed may be elaborated so as to deal with other features of scientific growth, for example, the manner in which work along lines D_2 and D_3 reflects on continued progress along D_1. Thus, after the early falling-off of contributions along the original lines of electrodynamics, interest was revived first by Maxwell's and Hertz's work in electromagnetic waves, then later by Lorentz's and Einstein's, and most recently by plasma physics.

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FRANK E. MANUEL

Two Styles of Philosophical History

THE TITLE of this essay might lead to the suspicion that its author has himself succumbed to the *morbus philosoph-historicus*. Some reassurance is therefore required from the outset. Far from presuming to dichotomize philosophical history in all times and places, these reflections are limited to two traditions, one in France, the other in Germany, during the period which might be called the classical age of modern essays in philosophical history—roughly from the middle of the eighteenth through the middle of the nineteenth century. There appear in this brief time span a sudden self-consciousness about the problems, a thematic richness, and a creative originality which render it unique; by contrast, late nineteenth- and twentieth-century philosophies of history sometimes seem to be the work of industrious epigoni, whose voluminous writings have filled the old bins with the harvest of modern historical scholarship, the chaff and the wheat.

The French chain of intellectual transmission runs from Voltaire and Turgot through Condorcet, Saint-Simon, the Saint-Simonians, and Fourier, culminating in Auguste Comte; the German one, from Winckelmann, Herder, Lessing, and Kant, through Schiller, Schelling, and Fichte, culminating in Hegel. Two towering figures will be conspicuously absent from this presentation: at the beginning, that lone Neapolitan, Giambattista Vico, and at the end, Karl Marx, with his synthesis of elements from both the German and the French schools. Vico is omitted because of my deep conviction that, despite his nineteenth-century translators in France and Germany and occasional quotations from his work, he had relatively little influence on either style. If Marx is looked upon as a great syncretic figure, his place is in another context.

As a body of literature the French and the German philosophies

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of history of this period have been examined from a variety of viewpoints. They have been used as prolegomena to action programs, often in conjunction with political movements of a nationalist or a social revolutionary character. They have been read devotionally as theodicies, or as descriptions of God's way among the nations, or as works of inspiration inducing an oceanic feeling which Freud thought kindred to religion and infanthood. (Thomas Churchill, the eighteenth-century English translator of Condorcet and Herder, has given naive expression to this latter sentiment.) In a paper a few years ago[1] I tried paradoxically to emphasize the empirical insights in these writings and their provocative juxtaposition of historical observations in a novel order. But these philosophies of history can also be considered in a different vein, not as things-in-themselves to be judged in their own terms, but as remarkable documents revelatory of something else—a general intellectual *esprit* prevalent in a given time and place. This is for me, moreover, not an isolated and discrete inquiry. A study of interpretations of ancient myth in eighteenth-century thought in 1959 has already presupposed that an investigation of a problem of this character (the nature of myth) can be fruitful in defining the mind and sensibility of an age.[2] Similarly, the rich modern cosmic and world-historical myths generally called philosophies of history can be studied as significantly expressive of mind and sensibility rather than as approaches to truth. They may be delusions to the positivistic historian, but what magnificent delusions! Almost as good as poetry. Finally, there is an even more pretentious, if less overt, purpose to my analysis: the philosophies of history in France and Germany in the classical period formed cultural personality as well as expressed it. Since they imprinted themselves upon national character, their mood outlasted the age of their composition; and sometimes their images persisted well into the twentieth century.

This is clearly a rash enterprise and ought to be undertaken only with the privileges of what the Germans call *Narrenfreiheit*. It involves riding rough-shod over the differences among the three Herders which Germanic learning has recognized, the young and the old Hegel, Saint-Simon before and after the insane asylum, Auguste Comte before and after his love for Clothilde de Vaux, and similar distinctions which have been made by laborious scholarship.

A word about the autonomous development of the two styles. The very idea of building a significant contrast between two schools of philosophical history in two late modern European nations which

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are divided by nothing more than the Rhine might well be questioned. But the facts are that the two styles did evolve in relative intellectual independence during this period. Of course many theoretical idioms are common to both of them, and one could profitably explore the resemblances; but this essay will concentrate on their distinctions. The two styles, while definable, are by no means absolutely pure, and some figures such as Diderot in France and Lessing in Germany do not fit very neatly into the categories; the polarity of the two types, in my judgment, is nonetheless illuminating.

In eighteenth-century Europe intellectual currents moved from west to east. That group of creative Germans in far-off East Prussia (Kant, Hamann, and Herder) read all the important French books at a time when French thinkers hardly deigned to peruse what any German was writing. Yet, though Herder and Hegel actually journeyed to Paris, their contact with French thought aroused in them only hostility, negation, and ultimate rejection. In one of his last lectures on the *Philosophy of History*, Hegel pontifically excommunicated all the Romanic nations:[3] "With them the inner life is a region whose depth they do not appreciate, for it is given over 'bodily' to particular absorbing interests, and the infinity that belongs to the Spirit is not to be looked for there."

Similarly, the impact of the German philosophers of history on the French was negligible. By the time Herder, Lessing, and Kant were translated, the foundation and framework of the French structure had already been erected. Though Victor Cousin was a fashionable Parisian lecturer on German thought during the last years of the Restoration, it is highly dubious whether his much-touted transmission really "took" in the first half of the nineteenth century. Saint-Simon had made a brief trip to Germany early in the century, but he always spoke ill of the German romantic spirit. When the Saint-Simonians were forging their doctrine in dramatic closeted debates in 1829 and 1830, the term "Hegelian" was a scornful epithet hurled at metaphysical quibblers. If the Saint-Simonians borrowed the concept of Antagonism from Kant's essay on universal history, they grafted a completely different meaning on it. It is reported that Hegel said a few kind words about Comte to his friend Gustave d'Eichthal and that Comte reciprocated by including a Hegel Day in the Calendar of Humanity, but that was the extent of their communion.

There is one momentous exception to this thesis of autonomous development, however, and that is the ubiquitous Jean-Jacques

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Rousseau. His apotheosis by the French revolutionaries only superficially identifies him with the rationalist, activist, progressive spirit which that political event came to represent in modern history. Rousseau the pietist from Geneva belongs to the pietists of East Prussia; it was fitting that he should be repudiated by Parisian intellectuals and comprehended in all his profundity only by the Germans, by Kant and by Herder. If the *Emile* is a *French* treatise on education, based on principles of reasonable utility, natural virtue, benevolence, and fellow-feeling, the real tragic history of mankind depicted in the *Discourse on Inequality* and the nightmarish self portrait of a totally alienated man in the *Confessions* are documents whose essential meaning was understood above all by the Germans, and these are the works whose spirit informs their philosophies of history. Karl Barth has rightly claimed Rousseau for the German Protestants. The moments of illumination before the composition of the Dijon prize essay, which Rousseau has himself described in a letter to M. de Malesherbes, are in the character of a sudden conversion:[4] "All at once my mind seemed dazzled by a thousand lights . . . my head swam with a dizziness akin to drunkenness." Rousseau's discovery of man's secret inner nature was a religious experience, and by the same token it was foreign to the Baconian methods of acquiring and diffusing knowledge that were hallowed by Turgot, Condorcet, Saint-Simon, and the positivists.

First to the Frenchmen. By the time Voltaire invented the term *philosophie de l'histoire* in 1765,[5] Turgot had already delivered his famous harangues before the Sorbonne on the successive "progressions of the human mind," a title which was preserved by his protégé Condorcet in the famous *Esquisse* of 1795. As if in reply to Montesquieu's anatomy of the fall of Rome, these philosophers demonstrated that the values of contemporary French scientific and rationalist society would endure forever, growing in strength throughout all time: the modern Antonines would never decline. Because of the cumulative effect of scientific knowledge—in a Baconian sense—regression was impossible. The French had already reached a high level of intelligence, and there were still loftier summits ahead. Or, as Herder mocked the Encyclopedists in his first essay on philosophical history, "We are the top of the tree, swaying in the divine breeze."[6]

The problem of man had been solved; scientific method, now universally appreciated, had projected a roadway into infinity.

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Progress was irreversible and indefinite, by which Condorcet in his *Esquisse* meant that only from a greater height could one even conceive of the future prospects for mankind in terms of pleasure and power over nature. By wresting from nature its own secrets, its laws, he wrote in a manuscript, nature could be tamed. In the future man would enter the lists an equal in power with nature itself —one of the grandest expressions of hubris in an age not characterized by excessive humility.

World history was the record of man's steady conquest of the external world, beginning in a period when he was still weak and feeble and culminating in his present high estate. In the struggles of the past, victims had fallen by the wayside, but human action, always guided by the pain-pleasure principle, had kept fairly well to the road. Pleasure and desire had led man onward, and so had the mild but necessary irritability engendered by pain. The historical process could be represented as a series of needs, their appeasement, and the creation of new needs in the course of satisfying the old ones, ad infinitum.

An element of conflict had been introduced into history when wicked corps (tyrants, priests, cliques of philosophers) had monopolized the instruments of power, of knowledge, and of pleasure. The corps spirit had suppressed novelty, Turgot charged in the *Discourses*. But the stagnation periods had never endured very long: men broke the bonds of sameness, gathered fresh impressions, promulgated new ideas, and found adherents among the rulers themselves. For who could long reject the instrumentalities which promise power and pleasure? Occasionally there were barbarian irruptions from the heart of darkness, but the new peoples were quickly assimilated as they acquired the tools of knowledge.

Condorcet, writing at a pivotal moment in the history of the idea of progress, raised the momentous question as to whether the liberty and the free inquiry which in the past had been the guarantees of progressive development might not in the future have to bend a little before the new demands of scientific organization. The rate of the rather haphazard development of the past might in the future be increased to an undreamed-of degree if the practice of science by organized bodies rather than by free-wheeling individuals were encouraged. Hence the impressive catalogue of world-wide controlled researches projected in Condorcet's *Fragment on the New Atlantis*. Since each scientific acquisition in the past had ultimately been transmuted into a quantum of pleasure distributed among man-

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kind, what a harvest of well-being and happiness was in store if the accumulative process of science and technology could only be accelerated through coordination. Condorcet the doctrinaire liberal in politics was willing to accept the imposition of external discipline on the republic of science for the sake of human betterment.

The movement of future progress described by Condorcet can be likened to the advance of the whole of mankind on an open plain. In the front rank, ahead of their fellow men, the scientific elite are dashing forward at a speed which is continually being augmented; behind the main body portions of humanity lag because they have been duped by Machiavellian despots and their priestly minions. But the forward thrust of the great cohort of scientists is of such Herculean power that it pulls the whole of mankind along with it. And as they advance in time, men are ever healthier, happier, more acute in their sense perceptions, telescopically and microscopically, more precise in their reasoning power, more equal in wealth and opportunity, more humane in their conduct.

There was a break in the French tradition when, in the romantic spirit of the nineteenth century, their philosophers of history abandoned a concept of man in which mind was a supreme capacity to which all other talents were subordinate. Once the Saint-Simonians and Comte defined man as a feeling and willing being whose capacities for love and action were of equivalent, if not superior, worth to his reason, history had to be reformulated as the progress of love or the progressive actualization of all human capacities instead of the development of mind alone. Nevertheless, the basic model of progress as a measurable extension of human welfare over ever broadening areas, at an ever faster tempo, was preserved.

True, Saint-Simon and Comte introduced new motifs—especially the idea of the conflict of classes and the concept of crises. But in the French view of the historical process the crises are always readily resolved; the standard formula was the defeat or abdication of an old ruling class and its replacement by a new one. Historical crises were the consequence of a mechanical disequilibrium in the manifest organization of civil society, which had failed to take account of the vast accretion of power in what were formerly subordinate groups. The ideal historical solutions were largely institutional: the creation of a new hierarchy, a more reasonable division of labor and power reflecting the new realities, the elimination of contradictions between civil and political power. The legions of adherents to the problem-solving school of historical interpretation who people

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our American universities are blessedly unaware of the degree to which they reflect this simplistic progressive style of philosophical history.

In this French school the process of historical change is remarkably continuous—perhaps its most significant characteristic. A stage or a period in Condorcet's *Esquisse* is merely a step on the ladder of progress. And steps merely punctuate the continuous progressions. The discoveries of genius are great moments in the historical ascent, but they have been prepared by a long series of little steps called gradual development. Historical movement is so inherently continuous that all periodization is in the final analysis arbitrary. One may recall that there are ten epochs in Condorcet's *Esquisse*, a rational number. How convenient of history to express itself in terms of the metric system! (In the same tradition, American texts on Western civilization run to fifteen or thirty chapters to fit the number of weeks in the school schedule.) Condorcet's favorite analogy to the historical process is a mathematical progression. Auguste Comte, who periodized history into three states, was still analyzing one long linear "social series"—his term. This same sense of a continuous process (without leaps or real disruptions) holds true even after dialectical elements were introduced by Saint-Simon, the Saint-Simonians, and Comte. They may talk about the organic nature of society (particularly the Saint-Simonians), but they really mean a clear and distinct group of elements which define progression and rest. Auguste Comte's sociological neologisms, Social Dynamics and Social Statics, sufficiently characterize the essential nature of this style; though Comte was learned in the new biology, he remained the mathematics tutor and polytechnician to the end.

Across the Rhine one is immediately struck by a different temper. The Germans who composed philosophies of history were either pastors like Herder, sons of pastors like Lessing, or state-university professors like Kant and Hegel. Germany was economically weak and politically divided, and despite the respectable positions occupied by the pastors and professors in their isolated principalities, they never presumed to affect directly the external political world. At most, they were educators. Lessing's hundred aphorisms were entitled *Die Erziehung des Menschengeschlechts*. The philosophies of history written by the Germans were educational treatises which, in describing how the human species was fashioned, were at the same time molding the inner beings of their

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students and their small, literate public. The Frenchmen who created the major themes of philosophical history were incorrigible activists—a king's minister, Turgot; a revolutionary leader, Condorcet; founders of movements and new religions like Saint-Simon, the Saint-Simonians, and Comte. For the Frenchmen the prospect of implementation was immediate; they themselves were bringing the new world into being, accelerating the projected historical series. Among the German pastors the militancy of a Luther had long since died. And in the university the distinction between the *vita activa* and the *vita contemplativa* was absolute. Kant never left Königsberg; and Hegel insisted that the owl of Minerva, philosophy's grey in grey, only takes flight at dusk. Contemplation *after* the event. To the traditional German academic of that epoch, the activism of the American professoriat and its direct manipulation of power would not be the least astonishing aspect of our way of life.

The German style of philosophical history mirrored the temper of these doctors of the inner life. In effect, the religious spirit of Luther—not his political style—informs virtually all the works of the Germans. While the French wrote a history of man's expanding capacities and his good works, the Germans composed a history of the inner man, a Protestant world history. The French systems were plainly sensationalist under the influence of Locke and Condillac; the Germans remained profoundly religious, whether their authors shunned the church building, as Kant did, or not. If religious residues remained in the French outlook, theirs was a vision of man triumphing through works. Cumulative progress is like a world treasury of merit to which the great scientific geniuses (the secular analogues of the saints) are all contributing their substance.

In the end, the French are therefore buoyantly optimistic, even when they are subject to moments of skepticism and doubt; the Germans are profoundly pessimistic, even though they may write about perpetual peace, the ultimate fulfillment of man's nature, and the conquest of Spirit. If the French school presents man's destiny as a utilitarianism temporalized or a history of pleasure and gratification, the Germans from Kant and Lessing down are writing a history of spiritual liberty and instinctual repression. Protestantism has taught them that illumination and knowledge of God were a long and arduous process which required extraordinary exertions, soul-searching, and the effort of will. The German philosophers of history have extended the history of individual God-seeking to the whole

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species. Even when they use words like *Fortgang* and *Fortschritt,* they do not mean what the French do by *les progrès.*

The Germans, at least Kant and Herder, felt that they were still living among Scythians, and their outbursts of despair and repugnance at the contemplation of their immoral contemporaries are frequent. "Everything in the gross is composed of madness, of childish vanity, and frequently of childish wickedness and the rage of destruction," Kant wrote disgustedly in *An Idea of an Universal History in a Cosmopolitical View.*[7] "Out of such crossgrained crooked wood as man is made of, nothing can be timbered quite straight."[8] For Schelling, history is a "tragic spectacle performed on the mournful stage of this world." If Hegel's spirit triumphs, it triumphs amid the death of cultures.

The French philosophers of history concentrate on the novelties; they revel in the material conquests and in the new acquisitions. They take a Baconian delight in sheer accumulation and in the variety of objects. They take pleasure in what Montesquieu called *le bonheur de l'existence.* For the Germans, who made world history into a *Bildungsroman,* the education of the human race was no lark. There is throughout these writings a sense of the pain and anguish of growth. They were dealing with a refractory pupil who kicked against the pricks and learned only through punishment. Man refuses to quit his minority, lamented Kant, anticipating Freud. The Germans were always conscious of the bloody travail of history, while among the French the philosopher's eye was focused on the growing ease and the new rationality.

The Germans, even the secularists among them, were weighted down by a sense of inborn evil. The baubles of French civilization they rejected with the moral righteousness of a Rousseau negating the arts and sciences. Herder could never accept the idea of perfectibility in terms of a mathematical increase of artifacts and powers. In the *Letters for the Advancement of Humanity* he posed the question rhetorically: "Or could perfection mean an augmentation in the number of tools and instruments for human force to use?" And he answered himself: "Were that so the question still would remain whether or not they were used for the good, since in the hands of malevolence greater instruments might signify greater evil."[9]

That simple reflection, which now strikes us so forcibly, obvious as it is, just never occurred to the French historians of the progress of civilization in the classical period. One should probably say "hardly ever," because there are inklings of this preoccupation in the last

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years of Auguste Comte. To the Germans it was the heart of the matter. Only moral *Innerlichkeit* counted, not objects. French enlightenment implied a progressive material increase in candle power until mankind, which had once been steeped in the darkness of superstition, would live in pure and clear, abstract yet distinct, ideas. For many Germans enlightenment meant metamorphosis, moral transformation, illumination in a religious sense, Paul at Damascus, a realization that to be man one must bear the burden of the categorical imperative.

When the Rousseauist conflict between natural man and societal man was resolved by the Germans, they invariably posited a giant leap into a new form of humanity. Historical time for them was discontinuous. It was expressed in Herder's image of the butterfly shedding the ugly worm-like skin of the caterpillar; in a pietist vision of the moment of sudden illumination, a breakthrough that metamorphoses man's moral nature, in a word, a religious conversion to morality with all the psychic appurtenances of new birth; in Lessing's prophecy of a Third Covenant.

The French philosophers were in one form or another writing histories of *bonheur* and *bienveillance,* and their happiness was a worldly one. The historical drama could be described as overcoming the impediments which mankind met in physical nature and in residual wicked instincts which had to be channeled or atrophied in order that *bonheur* might reign unchallenged. Fourier demanded a new social mechanism to attain *bonheur,* which for him involved nothing short of the complete abolition of repression and the proclamation of total instinctual gratification. "Pleasure is the perfect development of the existence of every living being," is an affirmation with which the French school—with the important exception of the later Auguste Comte—would have concurred, despite its tainted origin in one of the utopias of Restif de la Bretonne.[10]

With the Germans, the pursuit of happiness plays only a minor role in history, as in the last writings of Herder, or else it virtually does not exist. (Lessing's goal of *Glückseligkeit,* though nearer the French concept of happiness, is still far from *bonheur.*) Individual man may want happiness—he has desires and he has passions, *Habsucht, Herrschsucht, Ehrsucht*—but nature or the providential plan has quite another end for its creature—the total repression of his animality, as Kant taught. The attainment of consciousness, Kantian or Hegelian, does not create the happy fellow of popular imagery. Kant has left us a sketch of the ideal consummation of

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nature in human form (almost a self-portrait) in his essay *Observations on the Feeling of the Beautiful and the Sublime:* he is a melancholy man, anxious lest he fall from grace, lest he not obey the universal morality which he has internalized; and conscious of all the possible consequences of all his actions all the time. He is necessarily worried that he will inadvertently sin against the categorical imperative. "He is a severe judge as well of himself as of others, and not seldom tired of himself and the world."[11] In Arcadia, in innocence, men might be sheep-like and contented, but not in history. "Man wills to live commodiously and contentedly, but nature wills that he shall quit the state of laziness and inactive contentment."[12]

After Kant has argued himself into what he called a "heroical belief in the future history of virtue" in one of his last essays, *The End of All Things,* he carefully distinguishes this prospect from happiness or contentment. Such an idea might be applicable to timeless heaven where there is a monotonous chanting of hallelujahs, but in this world it must be excluded. "For the state in which man is at present always remains an evil compared with the better in which he is ready to enter."[13]

Turgot talked of four progressions—moral, mechanical, scientific, and aesthetic; Condorcet still used the plural, *les progrès;* for Saint-Simon and his school there were three progressions—rational-scientific, moral-emotive, and physical. To the French the world of the future was full of many things in motion. A Saint-Simonian dithyramb by Charles Duveyrier communicates the temper of the whole school:[14]

> Celebrations, scientific and industrial inventions, works, on land and sea, in the air, everywhere movement, a crowd yet the most perfect order, monuments, convents, shops, wonders of art, a blaze of colors, perfumes, concerts, dances, religious performances; and moral well-being, social and individual, love which grows, grows, grows, always, always!

For the Germans history had one end: the hard-won battle for consciousness, which is Hegel's Spirit, or the struggle for liberty which even in the secularist Kant is not far removed from Luther's Christian liberty.

Meaningful history to Kant would have been a depiction of the antagonism between the forces of sociability and asociability, which somehow leads to the development of man's nature in all realms beyond the instinctual and to its expression in institutions such as those of a just civil constitution. But the Kantian historical world

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view, which at first glance seems most committed to the concept of progress, and was read that way by many Frenchmen, was shot through with doubts. What will keep mankind from falling asleep, once the stimulus of antagonism has vanished? Who shall guard the guardians, is a perplexing question in another section of the essay on universal history. To the degree that Kant's universal morality was an absolute and indivisible whole, the partial historical achievements of morality and civilization did not impress him.[15]

Rousseau was not far wrong, he wrote,

> to prefer the state of savages, when this last step, which our species has still to ascend, is omitted. We are cultivated to the highest degree by art and science. We are civilized, to a troublesome degree, in all sorts of social politeness and decorum. But there is yet a great deal wanting to us to be considered moralized.

Condorcet's vicarious enjoyment of the future happiness of mankind merely through contemplation (this was his description of the philosopher's reward at the end of the *Esquisse*) was not the way for Kant. He could not be so readily compensated for the revolting spectacle before his eyes. There is more than mild disdain in the aged Kant's closing remarks in the second part of the *Disputation of the Faculties,* where he likened the contemporary wars of the nations to drunken brawling in a china shop.

If viewed mechanically and only in his lectures of the twenties, Hegel's history is a realization of consciousness and freedom and spirit in the world through time in a definable movement east to west; but it is hard to sense a triumphantly optimistic temper even in this work. Surely, if one accepts the centrality of the problem of bad conscience in Hegel's historical world view, as Jean Wahl does,[16] it is rather difficult to find the final dénouement of the historical drama convincing. The memory which lingers is the terrible contest of the individual and his collectives throughout time, inherent in the very split (*Entzweiung*) of being. In new birth, the pain and the torment predominate and become the essence of life.[17]

> Spirit will experience from nature not only opposition and impediments, but it will often see its endeavours fail because of nature, and often it will succumb as a result of the complexities in which it becomes entangled either because of nature or because of itself.

The Hegelian Spirit wrestling with itself is devoutly Protestant.

It is the state of contradiction which is creative, and for Hegel how miserably inadequate and superficial have been most past resolutions, especially the flat French eighteenth-century one. Is not

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Hegel's world history a history of the forms and self-tortured grimaces of alienation throughout time, as well as the victory of Spirit? In a few passages on the new industrial order and the psychological character of the alienated human relationships it was establishing, did not Hegel presage Marx's trenchant critique?

Seen through the eyes of the Germans, history is a holocaust. Hegel's Absolute Spirit has traveled from China to Germany, embodying itself temporarily in one world-historical state after another, nourishing itself on one national genius after another. Once a nation had reached its zenith, Spirit moved on to the next in order, leaving the soulless people to drag itself on through years of uncreative nullity, busied with politics and perhaps war, with a senile repetition of itself, until it finally died in the body, having long since been dead in spirit.

When history expressed itself in a world-historical figure, such a man trampled underfoot many a moral flower, because individuals had to be sacrificed to the course of Spirit. While hailing the triumph of the Idea and the Protestant German state in which it found its most complete expression, the final resolution of the conflict between objectivity and subjectivity, Hegel takes more than a nostalgic look backward to the Greek ideal of his youth; there is in him a longing for the image of spontaneous, beautiful Hellas which he had once shared with his friend Hölderlin. No German of his century was ever completely consoled for the death of the youth of mankind that was Greece. Thus, even for Hegel, the education of mankind, the fashioning of Spirit, entailed a maiming loss as well as a gain, as it had in Herder's first essay on philosophical history, in which he abandoned himself to a rather stilted analogy between the ages of man and the succession of civilizations from that of the patriarchal Middle East to the present. The Germans' fascination with the myth of Greece has been described too often to require further commentary: it obsessed virtually all the philosophers of history—Winckelmann and Herder, Schiller and Hegel. The French admired the heroic figure of Socrates as much as their neighbors did, but they knew that they themselves had surpassed Greece in science and morality and civilization, if not in art.

French philosophical history has been generally rather democratic and cosmopolitan. Despite the unshakable conviction that the French were in the vanguard of the historical process, the bounty of civilization was universally communicable to all races and peoples

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who were willing to assimilate and become a part of progressive history. The Saint-Simonians proclaimed with outstretched arms: "All shall be called and all shall be chosen."[18] For Comte, the whole of the past was embodied in the Great Being. Not so the Germans. It is with some sense of shock that we read Kant's summary dismissal of the black race as incapable of reason[19]—passages, by the way, which are omitted from the compendia by his devoted admirers.[20] To many Germans, meaningful historical activity was only the destiny of an infinitesimal body of the elect. Hegel was more selective than the most hard-bitten Calvinist. The actual living experience of most peoples was doomed to oblivion, in so far as the world history of the Idea was concerned. He wrote at the end of the *Philosophy of Right*:[21]

> Each of its stages is the presence of a necessary moment in the Idea of the world mind, and that moment attains its absolute right in that stage. The nation whose life embodies this moment secures its good fortune and fame, and its deeds are brought to fruition.

Yet at any given moment there is only *one* embodiment in *one* particular world-historical nation; events in all other nations at that moment of Idea are empty, devoid of meaning. All prehistory (life before the consolidated state) is without content; similarly, life in a nation that has spent itself, after its world-historical moment is passed, is treadmill activity, repetitive; the nation is a living corpse —it does not matter when it actually perishes. Hegel's *World History* is really a history of rare moments of perfection in a succession of national cultures. There are chosen moments in four or five chosen cultures. For the rest, there is nothing but inchoate barbarism or else decay.

In Hegel's *Philosophy of Right* the awesome exclusiveness of the Idea is expressed with a thunderous crash befitting a *Weltgericht* handing down its verdict:[22]

> The nation to which is ascribed a moment of the Idea in the form of a natural principle is entrusted with giving complete effect to it in the advance of the self-developing self-consciousness of the world mind. This nation is dominant in world history during this one epoch, and it is *only once* that it can make its *hour strike*. In contrast with this, its absolute right of being the vehicle of this present stage in the world mind's development, the minds of the other nations are without rights, and they, along with those whose hour has struck already, count no longer in world history.

What happens when a nation is passé?

> Perhaps it loses its autonomy, or it may still exist, or draw out its exist-

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ence as a particular state or a group of states, and involve itself without rhyme or reason in manifold enterprises at home and battles abroad.

The debris of history—the Marxist concept, which the Russians have adopted to depict the losers in the struggle—is profoundly Hegelian.

Herder's *Volk* cultures, too, had only a fleeting moment of excellence. In each *Naturvolk* there is a form-giving period during which national genius and the environment coalesce to bring forth unique creations in myth, poetry, and music; but the *Volk* culture is doomed to seek dominion and through overextension to find its genius corrupted. The world has witnessed thousands of these cultures passing through their biological cycles, and, in accordance with the dogma of romantic plenitude, thousands more will be born and will die. Herder's historical world literally pullulates with cultures dashing through their life cycles.[23]

> No *Volk* has long remained and could remain what it was. Like every art and every science and what-not in the world, each *Volk* has had its period of growth, flowering, and decline. And each of these changes has lasted only the minimum period of time which could be afforded it on the wheel of human fate.

Of one thing, he asserts, you may be certain: the culture now at its apogee is about to fall—Herder's eye is cocked on the French as he foretells the doom; and the cultures that are still close to nature (perhaps the Germans' and the Slavs') are bound to flourish. In Winckelmann's history of Greek art, the prototype for all German genetic theories, absolute perfection lasted but an instant somewhere between the second and the third stages of the cycle. The rest was a descent to inevitable death in sterile imitation—*völlige Untergang*.

Since for the French man was endlessly malleable and his reason easily amenable to new truth, there was nothing inherently necessary in a long hiatus between the discovery of a truth and its implementation. The speed of change depended on the wills of men, which could be appropriately organized for maximum output. The French *philosophes* from Turgot down, with their geometric pattern of enlightenment—blocks of darkness which presented danger and of light which in time would penetrate the black—expected this conversion of superstition to scientificism to take place as fast as possible. Even Auguste Comte, the Frenchman most committed to a stadial theory, nevertheless argued in the *Positive Polity* that the contemporary savage world could be rapidly changed from fetishism to scientificism (under the appropriate tutelage of Parisians, of

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course), skipping the intermediary stages through which western Europe had passed.

Beginning with Herder, German philosophical history was bound to a slow genetic sense of time. Benign transformations in national genius had sometimes taken place through the penetration of its hard core, but only with the passage of ages. For each being, each *Volk*, for Mankind itself, there was an appropriately ordained time span of growth and decay, and there is nothing that organized wills can accomplish to affect genetic time. In Aphorism 89 of *The Education of Mankind,* Lessing, though paying homage to the genius of Joachim of Flora and his prophecy of the third kingdom, chided his medieval predecessors because they were premature: "They believed that they could make their contemporaries, who had hardly outgrown their childhood, without enlightenment, without preparation, all at once into men who would be worthy of their third age."

In Hegel, World Spirit itself was obliged to suffer laboriously through cycle after cycle, in a whole series of cultures, from China to Germandom, and there was nothing which could have accelerated this tragic trek. From genetic time there is no appeal. To interfere in a life process, a nation's natural historical development, means to destroy its inner being. That is what the colonial powers have been doing to the savage and barbaric peoples of the earth, Herder charged in a summary of world-travel literature. That was the danger in a Frenchified king of Prussia addicted to *raisonnement* and orderliness and despotic rationality quickly imposed; he was killing the German spirit. That was the evil of even political freedom when it was imposed as a foreign yoke (Herder meant the French Revolution). "Therefore a history which justifies everything in all countries on the basis of this utopian plan [of the best governmental form] is a dazzling history of deceit."[24]

Perhaps in the contrasting sense of historical time we perceive the most fundamental difference between the French and the German philosophies—the one continuous and subject to rapid acceleration, the other profoundly discontinuous and beyond human will. In one the marking of divisions is extrinsic, in the other it is intrinsic. One is a history of events, the other a history of human nature. Though both use a terminology that betrays a common Christian origin—*esprit* as in *Saint Esprit* and *Geist* as in *Heilige Geist*—the French wrote a history of the *achievements* of the human mind (to amend Condorcet), the Germans a history of Spirit itself.

It would be supererogatory on my part to offer examples of the

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endurance of the French model of philosophical history in our time. It is the sea around us; from historical doctrine it has become official dogma. The German style, too, has persisted in twentieth-century philosophies of history—perhaps most of all in the writings of Protestant theologians educated in the German tradition. Even in Spengler, despite some of his disparaging references to the philosophies of history by Herder, Kant, and Hegel in his introduction to the *Decline of the West* and his different conception of historical morphology, one can still discern the same pervasive tragic spirit, the same genetic sense of time, and the same basic concept of cultural exhaustion. In my judgment he is deeply rooted in those thinkers of his culture whom he repudiated in his eagerness to appear the bolder innovator. Surely, his most fundamental analytic tool—the distinction between a creative moment called culture and a long decline known as civilization—is an echo of the German philosophies of history of the classical period.

By the second World War, one must admit, however, the national character of these two types of philosophical history no longer holds. In a strange spiritual transvestism, the two attitudes represented by the French and by the Germans have switched sides. The French have recently taken Hegel to their bosoms. Simone de Beauvoir reports somewhere that the day the Germans entered Paris she found herself reading him in the Bibliothèque Nationale—a double conquest. Conversely, it would appear that the Germans have had enough of *Innerlichkeit,* and that the break with their philosophical tradition is all but complete. The new West Germany has risen out of the ashes to a material acquisitiveness and practicality which seem to have brought heaven-on-earth to Frankfurt-am-Main.

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Religion, Scholarship, and the Resituation of Man

IN TODAY'S TECHNOLOGICAL society, what does religion expect of scholarship, in particular, of humanistic scholarship? The grounds of the question and of any acceptable answer are not what they would have been a few generations ago. The operations and range of humanistic scholarship have shifted, and the relationship of religion to human society has changed.

The vagaries of the concept of the humanities through the course of history are interesting and informative. Cicero, Aulus Gellius, and others use *humanitas* in the sense of liberal education, mental cultivation fitting a man, good breeding, elegance of manners or language, refinement—more or less synonymously with *doctrina, litterae, eruditio*. The concept was opposed to what belonged to mere brute animals, the infrahuman, and, by extension, to what was servile. By the fifteenth century the English cognate "humanity" is used somewhat in the sense of secular as opposed to sacred, as when William Caxton's edition of the *Golden Legend* speaks of a person as having "floured in double science . . . that is to say dyunyte and humanyte." The Renaissance, manuscript-oriented as the Middle Ages had been and further influenced by the invention of printing, tended to associate *humanitas* with reading and writing, giving particular play to the concept *litterae humaniores*. But this association of the humanities with letters helped dissociate the concept from philosophy. The subjects beyond grammar and rhetoric which were grouped under the generic name of "philosophy" were taught in the Middle Ages and much of the Renaissance by lecture and disputation without the use of written exercises. Under these conditions humane letters came to mean the study of grammar and of a rhetoric which was in practice, if not in theory, controlled far more by written expression than ancient rhetoric had been.[1] Since the study of

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literature as a formal discipline ended generally with rhetoric, to which poetry was more or less assimilated, the humanities were rather generally restricted to elementary and secondary schools until rather recent times, despite the plans of the great early humanists.

Today we vacillate in our use of the term; by the humanities we sometimes understand the study of literature and sometimes all the subjects covered by the term liberal education, that is, the broad or general fund of consciously cultivated knowledge which forms the core of our educational tradition and with which all educated members of society must be given at least some elemental familiarity. In a recent brilliant study, Alphonse de Waelhens describes the problem of humanism in phenomenological terms as that of "man facing his future and his past in his present situation,"[2] and explains that this problem is quite centrally one of expression, although, since all works of culture are modes of expression, humanism extends itself far beyond the arts of communication. The problem of facing the future and the past in the present, Professor de Waelhens points out, appears less acute at some periods than at others, but in our own time, with our high degree of self-consciousness, it is acute in the extreme. Here, although I cannot undertake to repeat Professor de Waelhens' brilliant and circumstantial analysis, I shall understand humanism in something of his sweeping sense, since this is certainly in accord with current usage as well as with his telling insights. Here, then, except when the context indicates otherwise, the terms humanism, humanities, and humanistic refer in this large sense to disciplines or activities centered in some manner around language and literature but including also the study of philosophy, history, religion in its historical and theoretical aspects, sociology, anthropology, mathematics, the fine arts, and related subjects.

When we take the term humanities in its large sense, we tend, somewhat hesitatingly, to oppose it to the physical sciences, or at least to technological subjects, however intellectually demanding such subjects may be. But we are not quite sure of our ground here, and our hesitancy hints at the existence of a problem, which is perhaps the great secular problem of our age: what is the relationship of man to things, particularly now that he is so much in control of them? Antiquity tended to oppose *humanitas* to the brutal. The ancient *humanitas* implied primarily a contrast between man and animal and, by extension, between an upper social class and a brutalized, servile social class. Today our concept of humanistic suggests

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more overtly a contrariety between man and a world of inanimate things (where work is not necessarily physically brutal at all). Our tendency to contrast the humanistic with the overspecialized reinforces this suggestion, for, in a society where details are becoming more and more the business of computers, specialization strongly suggests some sort of mechanization of intellectual function.

The changed relations between man and the physical world around him impart a nuance not only to the concept of the humanities but also to the way in which religion affects man's life. The central shift of religious interest here is that which has changed the relation between man and natural or cosmic religion. This shift, which began to be manifest at the time of the Enlightenment and has become spectacularly evident in our technological age, has affected those who profess a supernatural, revealed religion as well as those who profess a natural religion or no religion at all.

Man has never been entirely immersed in nature, for he has from the beginning adulterated it with his own fabrications. Nevertheless, in earlier times man had closely aligned his religiosity with the mysteries of nature around him, exploiting for religious purposes the sun and moon, waters, vegetation, and the whole panoply of natural objects which Mircea Eliade has discussed in his *Patterns in Comparative Religion* and which he, Jung, Daniélou, Beirnaert, and others have shown to have a kind of objective symbolic content accounting for and warranting their world-wide acceptance in quite diverse human cultures.[3] Religious attention to nature may be more or less pantheistic, but it is not necessarily so, and natural symbolism is built into the monotheistic religions and even into those religions (Judaism and Christianity) which, in the terms of Eliade and others, inculcate a respect for history and time, rather than a flight from their terrors. Nevertheless, although the waters of baptism or the bread for the Eucharist and other such symbols have a permanent place in Christian life, this place is assured primarily by the fact of their connection with historical events of some two millennia ago when they were instituted, and with the symbolic sense which then reigned not only in Israel but through the world generally. If the symbolism in Christian rites were unsupported today by association with the realities of man's past, if this symbolism were launched for the first time in our abstract twentieth-century glare, it would hardly be convincing.

When pretechnological man addressed himself to nature and in

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or through it to God, he was addressing himself to something in which he felt himself deeply involved, from which he could not stand off in objective contemplation. Hans Urs von Balthasar distinguishes in man a threefold relation to truth: a relationship to the "coordinated being that meets him, usually and misleadingly called object of knowledge" (the relationship which engenders abstract science), a relation to the cosmos "based on his own bodily being and the immanence of the human spirit in the world," and "a relation of assent to the absolute and to the 'light' and the 'word' that flow into him from there because of his 'openness.' "[4]

Earlier religion, like much early philosophy of practical cast, such as Stoicism, drew heavily on the second of these relations, that based on man's own bodily being and spiritual immanence. Confronting the universe in terms of his continuity with it and immanence in it, supported by traditionalist institutions which he had little ability or desire to explain abstractly, early man felt strangely at home in the cosmos, even when it was doing him the utmost violence. By the same token, he had little occasion to encounter himself as distinct and alienated from his surroundings, alone. It was I-and-my-context or man-and-context which preoccupied the mind—a form of thought which Dorothy Lee finds persisting today in the concept of the self among "primitives" such as the Wintu.[5] In this pretechnological culture the concept of man is poetically rich because it has so broad a support, suggesting as it does so much else with which man is in contact. It was through this same world with which he felt himself continuous that early man's religiosity expressed itself.

From this world of nature man has pulled further and further away. He no longer feels much at home in it—although the relations with it, hinted at by known evolutionary processes and structures, are now opening the possibility of renewed acquaintance. Man's present changed relation to the cosmos has come about as the result of a long series of shifts, the basic sequence of which Auguste Comte tried to catch in his three-stage pattern of social development: the magic stage, the philosophical stage, and the scientific stage. Whatever the ultimate validity of this proposed description, we are now living in a different world from that of earlier man, one in which two principal termini of development can be conveniently located for our present purposes. These are mechanization and man's encounter with himself.

The mechanization effected by technology has a long history,

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running back to such distant sources as the quantification of thought in the Middle Ages.[6] It stands as one terminus of a great effort at abstraction, which has enabled man to hold things at a distance from himself, to extricate himself from his context and to deal with it as something in which he is purportedly for the moment not involved.

What I mean by man's encounter with himself is in a way a correlative of mechanization. For mechanization is an operation which affects not only man's efficiency but his very sense of his place in the universe and even his self-possession. To gain control over the material world, we have had to move away from it, in the sense that we have had to operate on it more and more indirectly. The old agricultural activities, for example, rich with folklore which emphasized man's continuity with nature, have been in great part replaced by activities still agricultural in aim but carried on in distant factories, in botanical laboratories, and in cost-accountants' books. As man's presence becomes more and more effective and his responsibility for the world more and more actual, his individual operations become more and more remote from the end result. Gadgetry intervenes between us and the universe at the very time when the universe appears within our grasp. The plight of the spaceman becomes symbolic. How will he ever be genuinely present to outer space, when he is so thoroughly insulated from it in his pressurized suit? And how will he be present to other men, and other men to him? The problem of survival in physical, personal isolation is one of the major problems of the space projects, which are in so many ways the most typical endeavors of our age. Man needs a sense of community to keep his own self-possession. Deprived of this sense, he is more than isolated or lonely; he is alienated or estranged from himself.[7] Technology works against the communal sense on several fronts at once, both openly and insidiously. It is not surprising that the themes of isolation and alienation have become a commonplace of literature and the arts today.

And yet this is no adequate view of technological society. Technological society has indeed created certain special conditions favoring isolation or alienation, but it has not invented these states, which have been long known to man, although they have been brought about by diverse causes in diverse cultures. We must not forget Lear and Hamlet and the bitter human experience which made these *isolés* plausible to their own ages, as well as to ours. As a matter of fact, moreover, mechanized, technological society has placed the

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conditions for the encounter of man with man on a basis more intimate than ever before. Society has not, of course, created this encounter, and it can even be perverted so as to prevent it. Only love can create a genuine encounter between man and man. But there can be no doubt that technology has made possible an enlargement of the range of love.

Technology has made possible the total exploration of the earth's surface. It has brought the separate human colonies scattered across this surface, unknown to one another for probably hundreds of thousands of years, into contact with one another, and it maintains this contact daily and hourly. The resulting sense of the solidarity of the human race is new, and it has immediate religious relevance. A Christian in the West today can live with a sense of involvement with his non-Christian brothers in Asia such as could hardly be acquired by medieval Christians, hampered as they were by the quasi-militarist concept of Christendom which was rooted in a lack of contact. Society has become more and more self-conscious about its responsibility for its individual members. Our development of communication, our study of personality structure, of intergroup relations, of depth psychology, of sociology, of the fuller significance of literary and art forms—all have made person-to-person relations accessible to explication as never before. To explicate relations between man and man is of course not to create them. For this, love is necessary. But I see no indication that love is less active today than it has been in the past, provided that we view the past as it was in actuality and not in some romantic transformation.

The preoccupation with isolation and alienation in our literature is itself an encouraging sign, for to know one's disease is to increase the possibility of a cure. The present trend toward isolation and estrangement, with its special roots in technological society, has paradoxically called attention to man himself and his own human problems more explicitly than was ever the case before.

This does not, however, restore man to his context in nature. His estrangement continues in so far as his relation with nature is concerned. And this presents a special problem in man's encounter with his fellow men. His encounter with them is now relatively stark, naked, direct, rather than cushioned in the living forces of nature, real or imaginary. If man today feels that next year's corn crop may be threatened, he does not organize the community for a rain dance which, however meteorologically ineffective, at least in the past established a bond between man and man based on their common

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dependence upon natural forces. The farmer concerned about his crop nowadays consults an agricultural expert to find what sort of hybrid seed corn is available, produced especially to fit the rain patterns of his particular area. He and the agricultural expert are not linked to nature as to something on which both depend to the extent that obtained in the past. The two are managers of nature, meeting not in nature but above it, looking down on it.

Under these conditions, human encounter takes on a new importance because of its starkness. Outside nature, men are all alone —but they are all alone together. They are more obviously than ever one another's context. One can describe the situation in the terms which Ludwig Binswanger has made current in phenomenological and existential psychology, the *Umwelt*, the *Mitwelt*, and the *Eigenwelt*, which represent three modalities of man's world.[8]

By the *Umwelt*, Binswanger refers to the world of objects about man, the natural world, the world which man shares with other animals, in short, approximately what we mean by environment. The *Mitwelt*, on the other hand, belongs to man alone: it is the world of interrelationships with human beings. This world differs drastically from the environmental world, for action within it is personally reciprocal. It is the world of personal relationships, of encounter between man and man. Here one individual does not influence another in the way in which environment influences us, for in encounter one man influences another in so far as he himself is influenced by the other. For me to become acquainted with you does something not only to me but also to you—one can only hope that it is not too disastrous. The *Umwelt* by contrast is inert: environment is not expecting us, in the way another person is. Binswanger's third world, the *Eigenwelt*, one's "self-world," is the one in which one encounters, faces up to, lives with oneself. It, too, is a world known only to man.

These three worlds, or "three modes of world," are interrelated, and the disruption of one necessarily disrupts the others. Within the past few centuries, and more intensively within the past few generations, as the *Umwelt* has become more subject to him, man has consequently had to turn his attention in some ways more to the *Mitwelt* and to the *Eigenwelt*, to make special adjustments.

As he looks out on the world today, man's chief problem is thus himself. We do not genuinely worry any longer about technological advance—perhaps we never did, for advance thrives not on worry but on enthusiasm. Although one or another technological problem may enter deeply into the concern of one or another individual

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whose work is technological, collectively we are not troubled about technological development. Given time, it will come, somewhere or other. We even state in advance and in public how many years it will take to be able to shoot a dog or a man or a space ship into orbit. But we *are* concerned about ourselves. From the university professor's lectures to the Sunday supplements, we find the same theme harped on: Can man survive his own responsibility? Accidents still happen, and they always will in individual lives. But more and more, when things go wrong, it is likely to be not nature but man who is accountable. He has failed in properly running through the count-down.

This situation of man has profound religious implications. Heretofore the religious matrix was I-and-my-universe (including other men) open to God. Now, with the physical world more and more at our command, the religious matrix is becoming more and more I-alone or we-alone open to God. In the perspectives suggested here, one can see some reason for the puzzling fact that, as technology has become more and more dominant, personalist philosophies, philosophies of "presence," of encounter, and of dialogue come more and more to the fore. It is not merely that the depersonalization enforced by technology generates a personalist approach to existence by way of compensation, although this is a partial explanation. At least equally cogent is the fact that man's control of things has made objects or anything treated as an object less fascinating in many philosophical circles than formerly. One turns from objectivity to intersubjectivity, not simply because one is overwhelmed and surfeited with objects but because one finds the more central problems really are the intersubjective ones.

In the shift from a world in which man finds himself embedded in nature to one in which he finds himself more and more externally managing nature lies the core of the problem concerning the relation of religion and the humanities today, if by the humanities we mean those disciplines which are of special concern to man as man and to his place in the scheme of things. For this place itself is undergoing a profound change. One still comes across explanations of the state of humanistic studies and of religion which querulously imply that the secularization of life and the increased prestige of technology are due to some kind of *trahison des clercs*. This is a provincial explanation which fails to get to the bottom of the problem, for what has been at work is not a greater and greater willingness of humanistic scholars or religious men, first Western and now Eastern,

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to compromise with the mechanics in the pits, but a major development having to do with man's gradual discovery of himself in the universe, a discovery connected with much larger movements, such as the growing together of isolated cultures, the development of mass languages, of exploration, of communications, and the extrusion of the mechanistic, technological armor which was the price man had to pay for freeing himself more fully from a contingent environment.

The occurrences of the past few centuries which are relevant to the present discussion can be summed up as follows. After a very slow start and an initial diffusion in tiny pockets across the surface of the globe, man has gained more and more mastery over the physical world. The knowledge and techniques developed by one or another group of people have been communicated to others as the scattered human colonies grew in size and finally established permanent contact with one another. The concomitant processes of populating the earth to an efficient density, gaining control over natural processes, and improving communication are by no means complete, and doubtless never will be, but the general pattern of consolidation and subjugation is unmistakable. At the present time man tends to find himself less embedded in nature, in the sense that he is less able to turn to it for psychological refuge, for nature is less his mother now than heretofore and is rather something over which he has assumed responsibility. As man looks out on the globe today, he more than ever finds that he is face to face with himself. This is the age of man's encounter with man. Such a fact cannot fail to affect the meaning of humanism. And it cannot fail to affect man's encounter with God.

Under the present circumstances, when man is plunged into a stark encounter with himself because of his new dominance over physical forces, there is one answer which immediately suggests itself to the religiously committed person when we ask what religion can expect from the humanities. One may simply respond that religion expects more and more attention to man as a religious being. But this answer is trite and unilluminating. Religiously committed institutions and persons presumably know of the need to be aware of man's religious activities, and, for religiously uncommitted or partially committed scholars and institutions, detailed suggestions concerning possible lines of thought and action which throughout the curriculum would call more attention to man as a religious being

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have already been spelled out in a number of volumes—for example in *Liberal Learning and Religion* or in *Religious Perspectives in College Teaching*.[9]

I shall pass over what these and similar books have treated and consider the question on a more fundamental level. Under the present circumstances, what religion would most welcome from humanistic scholarship, I believe, is the resituation of man within the natural universe, from which his quite unavoidable development of technology has removed him. When I answer the question this way, I am of course speaking from the viewpoint congenial to the Judaeo-Christian tradition—at least, to the extent that I am supposing that man's situation within the material universe is a matter of positive religious interest, that his viatorial status is not something of itself evil, and that, while it is the business of religion to keep man from making too much of purely material things, it is not on the other hand the business of religion to insulate man from time, history, and materiality, but rather to orient him within the temporal and material universe in which he comes into being. Other religious traditions may regard the situation differently and consider time and matter as evils or illusions from which it is necessary to free man. Certain religious traditions which espouse such views have much to contribute to the Judaeo-Christian understanding of the universe, and I believe that a Christian such as myself has much to learn from them. Yet in the cosmos as we know it now, especially since the discovery of evolution, it appears that this negative or fearful or hostile attitude toward time and matter is no longer a viable one, although individual insights associated with it may prove to be of great, and even unique, worth.

The resituation of man within the physical universe is called for because, in trying to express and handle man's present problems, we have overspecialized of late in helping him to know himself as an interior consciousness, and neglected relating him to the cosmos in its sweeping evolutionary structures. Never has man been more articulate about his own interior. He is to some extent prepared by literary and artistic productions and by humanistic studies for the new situation in which he finds himself, that of encountering himself as man has never quite encountered man before. Poetry, fiction, and drama—not only in Rilke, Kafka, Bernanos, Marcel, or Sartre but also in protoexistentialists such as Henry James or Conrad—have presented us with a literature of alienation and encounter; and phenomenonological and personalist philosophies have developed

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many of the tools for analyzing the person-to-person relationship or its absence. Specifically religious thinkers such as Martin Buber, Eugen Rosenstock-Huessy, Hans Urs von Balthasar, and others have gone into the religious implications and the dynamics of the dealings between man and man in dimensions far beyond those ordinarily considered in a treatment of "social" life. In the United States the interaction of self and other, including the "generalized other," has preoccupied George Herbert Mead and his followers, and John Dewey and his school have seen communication as paramount in mental life. Since Wittgenstein, linguistic and logical analysis has taken a definite social turn opening into interpersonal relations. Psychology, anthropology, and semantics are all deeply concerned with intersubjectivity and the problems of personal identity.

Yet this kind of thinking, which provides such fine and real insights into the isolation of each individual human soul and the encounter between self and self, is not enough. Man does encounter himself in the universe today more starkly than ever before, so that he needs this kind of thinking; but he still encounters more than man. He still finds "things," the *Umwelt,* his physical environment. Indeed, although he is less intimate with nature, he is nevertheless related to it in greater detail than ever before. Especially since Darwin, one of the major intellectual enterprises of man has been that of pinpointing his connections with the physical universe in which he has put in his appearance. As the evolutionary universe has opened itself to us in the past few generations, the pinpointing has run back now, at least in sketchy fashion, over billions of years of past history. Man no longer has to rely on guesses to know fairly well where he came in.

This knowledge of man's physical place in the cosmos, in space and time, has, however, been assimilated hardly at all to his knowledge of his own interior. The *Angst* of the existentialist hero or antihero appears to have nothing whatsoever to do with what paleontology tells us of man's past. Space novels, even those of C. S. Lewis, are of little help. The more we situate man in space, the less we situate him in his own interior, and vice versa. When the phenomenologists probe his interior, they lose sight of the stars. Man seemingly cannot be relocated in nature any longer.

The difficulty lodges in part in the fact that man's connection with the cosmos today is established abstractly and intellectually, whereas earlier it was established emotionally and infra-intellectually. The primitive felt his world as the reality around him. With

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the rest of things he was in no physical contact and virtually no intellectual contact. Today we are intellectually in contact with the most distant places and times. We calculate the precise period and location at which civilizations emerged. Thus oneness with nature in terms of a felt internal experience means less and less, whereas continuity with nature as a documented fact means more and more.

What is needed in this situation is to unite the interior and exterior, to restore man to his home in the cosmos. It is obvious that in this mortal life man will not find his permanent home here. And yet the material universe is in some sense his home: his material body is a part of his person, and in Christian teaching it becomes again a living part of each individual in the resurrection. In the Preface in the Mass for the Dead (echoing 2 Corinthians 5:1) we read:

> Thus for Your faithful, O Lord, life is changed, not taken away, and when the house of this earthly stay has crumbled, an eternal dwelling is made ready for us on high.
>
> Tuis enim fidelibus, Domine, vita mutatur, non tollitur, et dissoluta terrestris huius incolatus domo, aeterna in coelis habitatio comparatur.

Even in this context of death and decay, the body is spoken of as a house or home (*domus*), with an ease which today is enviable. Advocates of both religion and the humanities commonly decry the materialism of contemporary man. But we must not forget that the remedy for materialism—making too much of merely material things—is not to be sought in getting away from material things, for this is quite impossible. Even the most high-flown varieties of Platonism will not help us here. Materialism is not cured by flight from this world but by establishing our bearings within it, by impregnating it with intelligence and love.

Because of their concern with the human center of the cosmos in one way or another, the humanities seem particularly qualified to help man resituate himself in the universe by relating his interior and exterior points of reference. Are there any salient developments in contemporary scholarship which particularly indicate that within this scholarship such a resituation may be under way? Those that exist, I believe, may be conveniently grouped under two headings: the growing tendency of historically oriented studies to focus in the present, and the growing tendency of a great many disciplines to group themselves around anthropology.

For some time humanistic scholarship has been historical and

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evolutionary in outlook and method. This point is obvious and commonplace. But within the historical outlook there is a growing tendency to give explicit attention to the present, bringing knowledge of the past to rest there. This tendency is evident, for example, in the sensitive area occupied by linguistic studies. Here, while it is true that research on ancient languages continues to make progress, a whole new area of interest in contemporary usage (from English to Hopi and beyond) has come into being. In the teaching of English literature, the center of activity has moved, in the United States at least, from Old and Middle English, past the Elizabethans and Jacobeans, into the contemporary period. Work on contemporary literature can easily be superficial; but even after the necessary culling, the bulk of truly serious work on contemporary writers is overwhelming and without a real counterpart in earlier ages.

At its best, the trend to an interest in the present is not at the expense of an interest in the past. On the contrary, the latter has grown. We are faced with a paradox: as modern scholarship penetrates farther and farther into past ages and cultures—for the farther we get from the beginning of things the more our common store of knowledge about the beginnings accumulates—our interest in the present proportionately grows. Of course, an active and detailed knowledge of both past and present is not held in one and the same mind or minds; but it is possessed by society as a whole, and it is accessible to those who wish it.

Often enough, therefore, serious literary scholarship brings a circumstantial and detailed knowledge of the past to bear on the interpretation of the present—as it is indeed forced to do in interpreting the works of a T. S. Eliot or a James Joyce. The conscious exploitation of the past for the illumination of the present which we find in creative writers such as Joyce and Eliot is itself significant. But the trend to a present-focused historicism is not due merely to the existence of such writers or artists. Rather, their work and that of scholarship itself follows a common trend, observable also in other fields. In sociology, for example, the study of primitive cultures has enriched, and profited from, elaborate studies of the societies in which the sociologists earn their livings. In political science, the study of contemporary institutions has become a major undertaking. In history itself, a deeper and deeper penetration of the past continues; but the historical documentation of the present (as, for example, with the Roosevelt, Truman, and Eisenhower collections) proceeds along an even wider front. And this is true of many other disciplines.

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This present-focused historicism undoubtedly manifests a growing interest in bringing our contacts with all reality to bear more immediately on man's present and future situation and thus to help him situate himself in the universe as a whole.

In *The Myth of the Eternal Return,* Mircea Eliade has shown how the concept of a Golden Age to which one dreams of returning represents a certain flight from time and the responsibilities of life in time. The present state of scholarship is such that a nostalgia for a Golden Age, which haunted even the learned in antiquity, no longer troubles us. Most nostalgic attitudes toward the humanities (certainly in learned circles) must be at least partly concealed to persist at all. The special kind of scholarly antiquarianism which marked the Renaissance and lingered on through subsequent centuries has now fairly disappeared. What antiquarianism we have appears not so much in scholarship as in Frontier Days' celebrations and other commercially stimulated folk activities, which scholars find it hard to take seriously, except (and this is highly significant) as manifestations of contemporary culture.[10] Yeats' "Byzantium" makes good poetry, but it does not tempt paleontologists or tease city planners out of the twentieth century.

Closely allied with the present-focused historicism of scholarship is its tendency to orient itself around an anthropological center. The older focus of attention on nature (in all the many senses of that word) in our day has yielded to a new focus on man and to a detailed study of man's relation to his environment quite unknown in earlier days. This anthropological shift has thus registered within the humanities themselves the changed status of man in the cosmos, his relative independence of nature and his growing success in subjugating nature to his own interests. Earlier philosophies talked of the dominance of the microcosm within the macrocosm, but this dominance was realized in a quite limited way.

The cultivation of anthropology as a field of inquiry had to wait until mankind had built up a certain population density around the earth, and then, by expanding travel and communication, had become conscious of itself as a whole and of the diversity and unity of the social structure. Anthropology is thus the product of the present stage of human self-consciousness. By now, anthropology has become a point on which a great many scholarly and scientific operations (perhaps in a sense all of them) more and more converge. This alliance with anthropology was noteworthy in philosophy from the nineteenth century on,[11] not only in those Continental currents

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which were to move into contemporary phenomenology and existentialism but also in Anglo-Saxon linguistic and logical analysis, in which an interest in the sociology of knowledge and the role of communication has been especially manifest since Wittgenstein. The alliance with anthropology was doubtless to be expected in paleontology, archeology, history, and psychology, but the anthropologizing which linguistics and semantics now entail—for example in work of the sort done by Bronislaw Malinowski and Benjamin Whorf—was hardly foreseen a few generations ago. Sociologists such as Johan Huizinga and Eugen Rosenstock-Huessy have entered into sociology and anthropology through the door of philology or even textual criticism—"grammar," in the large, classical sense of that term. Depth psychology, linguistics, and the weight of the sociological element in today's thinking have generally drawn literary criticism into the anthropological orbit. Northrop Frye's *The Anatomy of Criticism* is a good case in point: it is virtually impossible to decide whether this work is a literary or an anthropological study, for it is both, and very likely, in some sense, inevitably both. And even fields not commonly associated with the humanities, such as architecture, are quite explicitly caught up into anthropology, with the present developments in the sociology of city planning.

The present-focused historicism and the anthropological drift which mark scholarship in the humanities at this hour, even at their very center, where the humanities are concerned with human expression, language, and literature, represent trends which are religiously promising today. It is not easy to gauge trends so pervasive as these. Yet they appear to indicate that, as our scholarly knowledge of ourselves and the world around us grows, it is becoming more feasible to join a knowledge of intimate interior states to a knowledge of the exterior structure of the universe in time and space. A historicism focused on the present does something to the human consciousness that is different from what the more antiquarian variety does. Relating events from history and prehistory (which are always relatively external in their reported form) to man's sense of the here-and-now, it relates the exterior structure of the universe to a state of mind. For the present, in which alone man enjoys the interior sense of the *presence* of another (there is no *presence* in the *past*), is more directly personal and immediately interior than the past-as-past can ever be. The greater focus on the present in historical treatment thus represents not merely a shift from one "point" in time to another "point" (time really has no "points") but an altered state of

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mind affecting the exterior-interior relationship. The situation can be seen in *Finnegans Wake,* where past external events are transformed in a newly realized interior consciousness. Joyce's work is not, of course, precisely the same as that of a professional historian. Yet, more than the work of a professional historian ordinarily can be, it is directly representative of the contemporary historical state of mind. Ezra Pound's *Cantos,* shouting their author's defiance of the artificial order achieved by the selectivity of history and favoring more personal recollections, are representative in another but related way.

What we have styled the anthropological drift has similarly pulled the interior and exterior into a more explicit relationship with one another. Anthropology roots man in external environment, in time and space, descriptively and scientifically. Yet in doing so it in turn invites the relating of this external environment to man—which is to say, to an interiority, for it is in his possession of an inviolable interior, a personal conscious center, that man differs from other phenomena in the universe. When anthropological studies become involved with man's interior (as they are more and more), they develop their present keen interest in communication, which relates them not only to linguistic and literary studies, to psychology, sociology and philosophy, but also to something more directly religious —love itself. Informed work in communications today proceeds with an awareness of the human consciousness as a realm in which the interior and exterior meet, where interpenetration takes place between person and person. Fully informed studies of communication show an intimate awareness that communication and human knowledge, which is inevitably communication, cannot exist at all except in a context of love. At this point, scholarly interest abuts on what is specifically and centrally religious.

I do not mean to suggest that anthropology has fully succeeded in linking man's interior with the external world, but only that it gives promise of some more unitary vision. In the remarkable efforts of the late Pierre Teilhard de Chardin, we certainly encounter some kind of major anthropological and religious breakthrough. It would seem that the fascination which *The Phenomenon of Man* has for alert thinkers through the entire world today lies in the fact that it seeks to formulate, perhaps for the first time fully and consciously, the work which lies ahead of synthesizing our awareness of the person with our knowledge of the evolutionary universe. Father Teilhard was an anthropologist (more specifically, a paleontologist),

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who had, moreover, besides a Catholic priest's concern with the spiritual, a keen interest in depth psychology and in his own strain of phenomenology. He was not much taken with "humanism" as an ideal. I recall talking with him on one particular afternoon in the garden of the Jesuit house in Paris where we were living in 1951 and feeling him bridle a little, in his gentle and smiling way, at the term *humanisme*. "Ça, c'est fini," he protested with emphasis. To him, humanism signaled a harking back, an attempt to catch the world vision of fifteenth- and sixteenth-century man, possibly an educational system in which training (in literature at least) is an attempt to integrate today's knowledge around such a pole. Nothing, he thought, could be so futile. And I agree. If humanism can mean only this, we must have done with the term. We must indeed know the past intimately to know ourselves; but any synthesis must be a creation of our own time.

Religion, centered on God, is a unifying force; and from humanistic scholarship it demands as far as possible an integral view of man. Man's personal salvation, we can assume, is the business of religion itself. But religious man needs a knowledge of the whole background, as far as this can be ascertained, against which his personal salvation is being worked out. In the Judaeo-Christian tradition, the entire universe, no matter how far extended in space or time and no matter how deeply hidden in some of its aspects within man's consciousness, is seen as God's universe, despite its imperfections and despite sin. Alfred North Whitehead once noted that the scientific mind, which is traceable back to medieval Europe, has its roots in the Hebraeo-Christian tradition even more than in the Greek, because by believing in one God Who created all things without exception and Who was infinitely intelligent and wise, medieval Christians approached the universe with a conviction far beyond that of the pagan Greeks that everything in it ultimately admitted of explanation, no matter how difficult it might be to find what the explanation was.[12] Scholarship needs this kind of conviction to serve religion today—and very likely even to survive. Its maximum service to religion, as to itself, will be realized by continued dedicated work, specialized and generalizing, carried on under the persuasion that there is a unity to be found in the relations, however complex and however changing, between the human interior and the universe in which man has appeared.

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2. "Le problème de l'humanisme, dont on nous parle tant aujourd'hui, s'est posé à toutes les époques, car il n'est autre que celui de l'homme confrontant son avenir et son héritage dans sa situation présente" (Alphonse de Waelhens, *Existence et Signification* [Louvain: Editions E. Nauwelaerts, 1958], p. 143).

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5. See Dorothy Lee, "Notes on the Conception of the Self among the Wintu," *Explorations* (University of Toronto), 1954, No. 3, pp. 49-58, a revision of an article which appeared earlier in *The Journal of Abnormal and Social Psychology*, 1950, *14*: 538-543.

6. See Walter J. Ong, *Ramus, Method, and the Decay of Dialogue* (Cambridge: Harvard University Press, 1958), pp. 53-91, 306-318; cf. R. Hooykaas, *Humanisme, Science et Réforme* (Leiden: E. J. Brill, 1958), and John U. Nef, *Cultural Foundations of Industrial Civilization* (Cambridge: Cambridge University Press, 1958).

7. The term alienation and its cognates perhaps warrant a special note. From the ordinary dictionary sources, we learn the following: The English term "alienist" was first used largely as a legal term for a physician skilled in handling mental diseases; but the association of alienation with mental aberration goes back to ancient Latin. We find *alienatio* in Celsus and Pliny in the sense of an aberration of mind, a loss of reason, delirium. The term originally meant the transfer of property from one to another (*alius*), but then it came to signify also a casting off or aversion, in the sense of a withdrawal of warm, friendly feeling from another person (cf. the English "alienation of affection"). It is remarkable that out of this concept grew that of mental illness, loss of sanity, which is obviously conceived of by the early Latin-speaking world as an "othering," a separation from oneself (cf. the English "I am beside myself"). The key perceptions of contemporary existentialism thus seem to have obvious roots in the Latin past.

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Contributors: Karl W. Deutsch, Robert Frost, John G. Kemeny, Lawrence S. Kubie, Harold D. Lasswell, Wassily Leontief, Clarence Morris, Renato Poggioli, S. S. Stevens, Victor F. Weisskopf.

Science and the Modern World View (*Winter 1958*)

Contributors: P. W. Bridgman, Harcourt Brown, Jerome S. Bruner, Philipp Frank, Henry Guerlac, Howard Mumford Jones, Charles Morris, Robert Oppenheimer, Giorgio de Santillana, and others.

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Books Published from Issues of *DÆDALUS*

Virtually all the issues of *Dædalus*, in expanded form, appear also as books in hard covers. Inquiries about these books should be directed to their respective publishers.

Evolution and Man's Progress, edited by Hudson Hoagland and Ralph W. Burhoe (based on the Summer 1961 issue of *Dædalus*), Columbia University Press, 1962. $4.50

The Future Metropolis, edited by Lloyd Rodwin (based on the Winter 1961 issue of *Dædalus*), George Braziller, Inc., 1961. $5.00

Arms Control, Disarmament, and National Security, edited by Donald G. Brennan (based on the Fall 1960 issue of *Dædalus*), George Braziller, Inc., 1961. $6.00

The Russian Intelligentsia, edited by Richard Pipes (based on the Summer 1960 issue of *Dædalus*), Columbia University Press, 1961. $4.50

Culture for the Millions? edited by Norman Jacobs (based on the Spring 1960 issue of *Dædalus*), D. Van Nostrand Company, Inc., 1961. $4.95

The Visual Arts Today, edited by Gyorgy Kepes (based on the Winter 1960 issue of *Dædalus*), Wesleyan University Press, 1960. $6.00

Quantity and Quality, edited by Daniel Lerner (based on the Fall 1959 issue of *Dædalus*), New York, The Free Press of Glencoe, Inc., $4.50

Myth and Mythmaking, edited by Henry A. Murray (based on the Spring 1959 issue of *Dædalus*), George Braziller, Inc., 1960. $6.00

continued

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EDUCATION IN THE AGE OF SCIENCE, edited by Brand Blanshard (based on the Winter 1959 issue of *Dædalus*), Basic Books, 1959. $4.50

EVIDENCE AND INFERENCE, edited by Daniel Lerner (based on the Fall 1958 issue of *Dædalus*), The Free Press of Glencoe, 1959. $4.00

SYMBOLISM IN RELIGION AND LITERATURE, edited by Rollo May (based on the Summer 1958 issue of *Dædalus*), George Braziller, Inc., 1960. $5.00

THE AMERICAN STYLE, edited by Elting E. Morison (containing material published in the Spring 1958 issue of *Dædalus*), Harper and Brothers, 1958. $5.00

SCIENCE AND THE MODERN MIND, edited by Gerald Holton (based on the Winter 1958 issue of *Dædalus*), Beacon Press, 1958. $3.95

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Note on the M.I.T. Centennial

The International Conference on Scientific and Engineering Education was held on 3-6 April 1961 at the Massachusetts Institute of Technology in honor of its Centennial. The roster of invited participants, who numbered over one hundred and thirty, came from all quarters of the globe and represented some thirty nationalities. The discussion was arranged under four topics: Scientific and Engineering Education in Newly Developing Countries: Scientific and Engineering Education in Countries with More Advanced Technologies; The Interactions of Science, Technology, and Society; and The Implications of Science and Engineering for International Relations. Under these rubrics twenty-one communications were presented.

Seven of these papers form most of the present issue of *Dædalus*. After consideration, it was decided not to include any of the others, for a variety of reasons. Some of those that had served well to fire discussion might not be so useful in printed form. A few were overly general; others were too sharply focused on the particular problem or practice of a particular region, so that, unless other papers were commissioned, the subsequent report would be unbalanced.

Accordingly, we asked the editors of *Dædalus* to select the papers they thought would be of the widest general interest. It is their selection that constitutes this volume. To help anyone who wishes to investigate further, a list of all the papers presented is appended. Copies of these may be found in the Archives of the Massachusetts Institute of Technology; microfilm or other duplications may be obtained from the Director of Libraries of the Massachusetts Institute of Technology.

INTERNATIONAL CONFERENCE ON SCIENTIFIC AND ENGINEERING EDUCATION

The Massachusetts Institute of Technology Centennial
3-6 April 1961

James R. Killian, Jr.	Julius A. Stratton
Chairman of the Corporation, M.I.T.	President, M.I.T.
John E. Burchard	Jerome B. Wiesner
General Chairman, M.I.T. Centennial	Chairman, International Conference

The italicized names following are of those who presented papers.

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A. Scientific and Engineering Education in Newly Developing Countries

Chairmen: Norman C. Dahl, Professor of Mechanical Engineering, M.I.T.; Everett E. Hagen, Professor of Economics, M.I.T.; James McCormack, Vice-President, M.I.T.

Participants:

Abdul Jabbar Abdullah, President, University of Baghdad
Jaime Benitez, Chancellor, University of Puerto Rico
Francis Bitter, Professor of Geophysics, M.I.T.
P. M. S. Blackett, Head, Department of Physics, Imperial College of Science and Technology, London
William W. Buechner, Professor of Physics, M.I.T.
Nabor Carrillo, Mexican Nuclear Energy Commission
Jaime H. de Sola, Student, M.I.T.
Jane Drew, Architect, England; Bemis Professor of Architecture (Visiting), M.I.T.
Ismael Escobar, Director, Cosmic Ray Laboratory, La Paz, Bolivia
Paulino J. Garcia, Chairman, National Science Development Board, Republic of the Philippines
Rolando Garcia, Dean, Faculty of Exact Sciences, National University, Buenos Aires
Harold L. Hazen, Dean of the Graduate School, M.I.T.; President, Robert College, Istanbul
Muhummad Qudrat-I-Khuda, East Pakistan Council of Scientific and Industrial Research
D. S. Kothari, Head, Department of Physics, Delhi University
W. Arthur Lewis, Principal, University College of the West Indies, Kingston, Jamaica.
William Ted Martin, Head, Department of Mathematics, M.I.T.
Max F. Millikan, Professor of Economics; Director, Center for International Studies, M.I.T.
Robert S. Morison, Director, Medical and Natural Sciences, The Rockefeller Foundation
Salwa C. Nassar, Professor of Physics, American University of Beirut
Davidson Nicol, Principal, The University College of Sierra Leone, West Africa
Eni Njoku, Professor of Botany, University College, Ibadan, Nigeria
Lucian W. Pye, Professor of Political Science, M.I.T.
Norman F. Ramsey, Professor of Physics, Harvard University

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Arthur Roe, Head of Planning Group for Education and International Activities, National Science Foundation

Abdus Salam, Professor of Theoretical Physics, Imperial College of Science and Technology, London

Mustafa Santur, Professor of Electrical Engineering, Technical University of Istanbul

Nevin Scrimshaw, Head, Department of Nutrition, Food Science and Technology, M.I.T.

Shukri Shammas, Director of Contracts, Contracting and Trading Company, Beirut

Salimuzzaman Siddiqui, Chairman, Council of Scientific and Industrial Research, Pakistan

Louis D. Smullin, Professor of Electrical Engineering, M.I.T.

M. S. Thacker, Ministry of Scientific and Cultural Affairs, New Delhi

Carroll L. Wilson, Professor of Industrial Management, M.I.T.

J. Tuzo Wilson, Director, Institute of Earth Sciences, University of Toronto

Jerrold R. Zacharias, Professor of Physics, M.I.T.

B. Scientific and Engineering Education in Countries with More Advanced Technologies

Chairmen: Edwin R. Gilliland, Head, Department of Chemical Engineering, M.I.T.; H. Guyford Stever, Professor of Aeronautics and Astronautics, M.I.T.

Participants:

John F. Baker, Head, Department of Engineering, Cambridge University

William O. Baker, Vice-President, Research, Bell Telephone Laboratories

Carl W. Borgmann, Director, Program in Science and Engineering, The Ford Foundation

Gordon S. Brown, Dean, School of Engineering, M.I.T.

Sanborn C. Brown, Professor of Physics, M.I.T.

Secor D. Browne, Vice-Director of Libraries, M.I.T.

Piero Caldirola, Director, Institute of Physics, University of Milan

H. B. G. Casimir, Philips Research Laboratories, Eindehoven, Netherlands (not present in person)

Paul F. Chenea, Head, School of Mechanical Engineering, Purdue University

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Morris Cohen, Professor of Physical Metallurgy, M.I.T.
Sir John Cockcroft, Master, Churchill College, Cambridge University
Bryan Coleby, Member of the Office of the Science Advisor, Paris
Martin Deutsch, Professor of Physics, M.I.T.
Charles Stark Draper, Head, Department of Aeronautics and Astronautics; Director, Instrumentation Laboratory, M.I.T.
Peter Elias, Head, Department of Electrical Engineering, M.I.T.
Francis L. Friedman, Professor of Physics, M.I.T.
Nils Gralen, Head, Swedish Institute for Textile Research
Sir Willis Jackson, Director of Research and Education, Associated Electrical Industries Ltd., Manchester, England
E. Knuth-Winterfeldt, President, Technical University of Denmark
Issac Koga, Professor Emeritus; former Dean of Engineering, University of Tokyo
Alexander G. Korol, Research Associate, Center for International Studies, M.I.T.
Lawrence S. Kubie, Psychiatrist; Director of Training, Sheppard and Enoch Pratt Hospital, Towson, Maryland
Erkki Laurila, Vice-Rector, Finland Institute of Technology
Francis E. Low, Professor of Physics, M.I.T.
Herwart Opitz, Director, Machine Tool Laboratory, Institute of Technology, Aachen
R. E. Peierls, Professor of Mathematical Physics, University of Birmingham
August Rucker, Professor Ordinarius, Technical Hochschule, Munich
Ascher H. Shapiro, Professor of Mechanical Engineering, M.I.T.
John C. Sheehan, Professor of Organic Chemistry, M.I.T.
C. Richard Soderberg, Institute Professor Emeritus, M.I.T.
Jeffrey I. Steinfeld, Student, M.I.T.
Shun-ichi Uchida, Central Research Institute of Electric Power Industry, Tokyo (not present in person)
Manuel Sandoval Vallarta, Mexican Nuclear Energy Commission
Patrick D. Wall, Professor of Physiology, M.I.T.
P. Winkel, Philips Research Laboratories, Eindhoven, Netherlands

C. Interactions of Science, Technology, and Science

Chairmen: George R. Harrison, Dean, School of Science, M.I.T.
Douglas M. McGregor, Professor of Industrial Management, M.I.T.

Participants:

Raymond Aron, Professor of Sociology, University of Paris

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Sir Eric Ashby, Master of Clare College, Cambridge University
Pietro Belluschi, Dean, Architecture and Planning, M.I.T.
Lucio Costa, Patrimonio Historica e Artistica Nacional, Brazil
Luther H. Evans, Senior Staff Member, The Brookings Institution
Gerald Holton, Professor of Physics, Harvard University
Patrick M. Hurley, Professor of Geology, M.I.T.
Aldous Huxley, Novelist and Essayist, Los Angeles, California
Roman Jakobson, Institute Professor, M.I.T.; Samuel Hazzard Cross Professor of Slavic Languages and Literatures, Harvard University
Howard W. Johnson, Dean, School of Industrial Management, M.I.T.
Humayun Kabir, Minister for Scientific Research and Cultural Affairs, Government of India (not present in person)
Abraham Kaplan, Professor of Philosophy, University of California at Los Angeles
Roy Lamson, Professor of English, M.I.T.
Edwin Land, Founder and President, Polaroid Corporation, Cambridge, Massachusetts
Max Lerner, Professor of American Civilization, Brandeis University, Waltham, Massachusetts
Sven Markelius, Architect and Town Planner, Sweden
Elting E. Morison, Professor of Industrial History, M.I.T.
David N. Ness, Student, M.I.T.
Derek de Solla Price, Professor of the History of Science and Medicine, Yale University
Jonas Salk, Commonwealth Professor of Experimental Medicine, University of Pittsburgh
Shmuel Sambursky, Professor of the History of Science, The Hebrew University of Jerusalem
Adam Schaff, Professor of Philosophy, Warsaw University
Irwin W. Sizer, Head, Department of Biology, M.I.T.
Hans Thirring, Professor Emeritus, Institute for Theoretical Physics, University of Vienna
A. V. Topchiev, Vice-President, The Soviet Academy of Sciences (not present in person)
Martin Trow, Professor of Sociology and Education, University of California
Shigeto Tsuru, Professor of Economics, Hitotsubashi University, Tokyo
Charles E. Wyzanski, Jr., United States District Judge, Boston
Arnold J. Zurcher, Vice-President and Executive Director, Alfred P. Sloan Foundation

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D. The Implications of Science and Engineering for International Relations

Chairmen: Alexander Rich, Professor of Biophysics, M.I.T.; Bruno B. Rossi, Professor of Physics, M.I.T.

Participants:

Pierre Auger, President, Committee for Space Research, Paris
Peter R. Bankson, Student, M.I.T.
J. Hendrik Bannier, Director, The Netherlands Organization for Pure Research
Lloyd V. Berkner, President, Graduate Research Center, Southern Methodist University
Homi J. Bhabha, Chairman, Atomic Energy Commission, India
Robert R. Bowie, Director, Center for International Affairs, Harvard University
Ritchie Calder, Journalist and Scientific Writer, England
The Rt. Hon. The Lord Casey of Berwick, Commonwealth Scientific and Industrial Research Organization, Australia
Sydney Chapman, Geophysicist, former President, Special Committee for the International Geophysical Year
Jule G. Charney, Professor of Meteorology, M.I.T.
Brock Chisholm, Psychiatrist, former Director-General of WHO
François de Rose, Ministry of Foreign Affairs, Paris
Amos de-Shalit, Director of Research, Weizmann Institute of Science, Rehovoth; Professor of Physics (Visiting), M.I.T.
Turhan Feyzioglu, Member of the Turkish Constituent Assembly; former President, Middle East Technical University
Lawrence S. Finkelstein, Vice-President, Carnegie Endowment for International Peace
Wolfgang Gentner, Director, Max Planck Institute, Heidelberg
Albert G. Hill, Professor of Physics, M.I.T.
Harry Hookway, Scientific Attaché, British Embassy, Washington
George B. Kistiakowsky, Professor of Chemistry, Harvard University
Charles Malik, Diplomat; former Lebanese Minister of Foreign Affairs; Professor, American University, Washington
Philip M. Morse, Professor of Physics; Director, Computation Center, M.I.T.
The Rt. Hon. Philip Noel-Baker, Member of Parliament, London
Norman J. Padelford, Professor of Political Science, M.I.T.
Ithiel de Sola Pool, Professor of Political Science, M.I.T.
Isidor I. Rabi, Professor of Physics, Columbia University

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Eugene Rabinowitch, Research Professor, University of Illinois

Hilliard Roderick, Deputy Director, Department of Natural Sciences, UNESCO

Walter A. Rosenblith, Professor of Communications Biophysics, M.I.T.

Walter G. Whitman, The Science Advisor, Department of State

Sir Solly Zuckerman, Professor of Anatomy, Medical School, University of Birmingham; Chief Scientific Advisor, Ministry of Defense

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